JAN 2 3 2015

Basis for EPA Approval of Minnesota's New or Revised Eutrophication and Total Suspended Solids Criteria in Accordance with Section 303(c) of the Clean Water Act

Contents

I. Introduction

On June 25, 2014, the Minnesota Pollution Control Agency (MPCA) adopted amendments to portions of Minn. R. 7050 and 7053. The amendments include eutrophication criteria for rivers and streams, the Mississippi River pools, and Lake Pepin; changing Minnesota's turbidity standard for rivers and streams, Mississippi River pools, and Lake Pepin to a standard for total suspended solids (TSS); and clarifying other aspects of Minn. R. 7050 and 7053. These amendments do not pertain to Minnesota's eutrophication criteria for lakes that EPA approved in 2008.

In a letter dated August 20, 2014, MPCA submitted the June 25, 2014, amendments to U.S. Environmental Protection Agency on behalf of the State of Minnesota for review and approval in accordance with Section 303(c)(3) of the Clean Water Act (CWA) and 40 CFR 131.20(c).

For the reasons described in this document, EPA approves in accordance with CWA Section 303(c)(3) and 40 CFR 131.21(a)(1) the following new or revised water quality standards (WQS) from Minnesota's amendments:

> Minn. R. 7050.0150, Subp. 4; Minn. R. 7050.0220, Subps. 3a, 4a, 5a, 6a and 7; and Minn. R. 7050.0222, Subps. 2, 2a, 2b, 3, 3a, 3b, 4, 4a and 4b.

Section II of this document summarizes relevant CWA WQS requirements. Section III explains the basis for EPA's conclusion that MPCA followed its legal procedures for revising or adopting WQS when MPCA adopted amendments to Minn. R. 7050. Sections IV-VI explain the basis for EPA's approval of the aspects of Minnesota's amendments that established new or revised WQS.

As explained in Section VII, EPA is not taking action under Section 303(c) of the CWA on the following provisions from Minnesota's amendments because they are not new or revised WQS:

> Minn. R. 7050.0150, Subps. 5, 5a, 5b and 5c; and Minn. R. 7053.0205, Subps. 7 and 9a.

II. Clean Water Act WQS Requirements

II.A. General WQS requirements

Water quality standards include "a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses." 40 CFR 131.3(i). Designated uses describe the manner in which states intend for their waters to be used and can include, but are not limited to, aquatic life uses that describe the type of aquatic life that should be able to use the water as well as recreational uses that describe the type of recreation humans should be able to use the water for. Criteria are numeric or narrative statements of the quality of water that must be present to support designated uses. Section 303(c)(2) of the CWA and 40 CFR 131.20(c) require states to submit new or revised WQS to EPA for review. EPA is required by Section 303(c)(3) of the CWA and 40 CFR 131.21 to review new or revised WQS to determine whether they are consistent with the CWA and 40 CFR Part 131.

EPA determines whether a particular provision is a new or revised WQS after considering the following four questions:[1]

> (1) Is it a legally binding provision adopted or established pursuant to state or tribal law?
> (2) Does the provision address designated uses, water quality criteria (narrative or numeric) to protect designated uses, and/or antidegradation requirements for waters of the United States?
> (3) Does the provision express or establish the desired condition (*e.g.* uses, criteria) or instream level of protection (*e.g.* antidegradation requirements) for waters of the United States immediately or mandate how it will be expressed or established for such waters in the future?
> (4) Does the provision establish a new WQS or revise an existing WQS?

II.B. Requirements pertaining to water quality criteria

"Water quality criteria" are defined at 40 CFR 131.3(b) as

> Elements of State WQS, expressed as constituent concentrations, levels, or narrative statement, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use.

Although MPCA refers to its amendments as "standards," the new and revised WQS that are included within those amendments only include criteria (as that term is defined at 40 CFR 131.3(b)); they do not include new or revised use designations. Consequently, EPA's review of Minnesota's new and revised WQS in this action is limited to reviewing whether those standards are consistent with federal requirements pertaining to new or revised water quality criteria. For

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[1] *See* EPA's *What Is A New or Revised Water Quality Standard Under CWA 303(c)(3)? Frequently Asked Questions*, October 2012 at http://water.epa.gov/scitech/swguidanceistandards/cwa303faq.cfm.

purposes of this basis for decision document, EPA will therefore use the term "eutrophication criteria" rather than "eutrophication standard" when referring to Minnesota's new and revised WQS that are under review.

40 CFR 131.11(a) provides that

> States must adopt those water quality criteria that protect the designated use. Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use.

40 CFR Part 131.6 requires, in relevant part, that states include the following when they submit WQS to EPA for review:

> (b) Methods used and analyses conducted to support water quality standards revisions.
>
> (c) Water quality criteria sufficient to protect the designated uses.
>
> . . .
>
> (e) Certification by the state Attorney General or other appropriate legal authority within the State that the water quality standards were duly adopted pursuant to State law.

40 CFR Part 131.5(a) provides, in relevant part, that EPA's review of WQS involves a determination of:

> . . .
>
> (2) Whether the State has adopted criteria that protect the designated use; [and]
>
> (3) Whether the State has followed its legal procedures for revising or adopting standards.

III. Minnesota Followed its Legal Procedures for Revising or Adopting WQS

For the reasons set forth in the August 25, 2014, letter to Dr. Susan Hedman, Regional Administrator for EPA Region 5, from Jean L. Coleman, an attorney with MPCA, EPA determines in accordance with 40 CFR 131.5(a)(3) that Minnesota followed its legal procedures for revising or adopting WQS when it adopted the new or revised WQS contained in the amendments to portions of Minn. R. 7050 adopted by MPCA on June 25, 2014.

IV. Eutrophication Standard for Rivers and Streams

Minnesota's rivers and streams eutrophication standard consists of multiple components: multi-indicator criteria for protection of aquatic life uses in rivers and streams that incorporate total phosphorus (TP), sestonic chlorophyll *a,* diel dissolved oxygen (DO) flux, diel maximum pH, and BOD_5 that apply to one of three ecoregions (or, in the case of the Crow Wing River and the North Fork of the Crow River, to specific transitional water body segments that border two regions); a separate benthic chlorophyll *a* criterion for protection of recreational uses in rivers and streams that applies statewide; and TP and sestonic chlorophyll *a* criteria for protection of recreational uses in the Mississippi River pools and Lake Pepin. Each aspect of Minnesota's eutrophication standard is separately addressed below, as follows:

Part A: Multi-indicator eutrophication criteria for rivers and streams (by ecoregion);
Part B: Multi-indicator eutrophication criteria for segments of the Crow and Crow Wing Rivers;
Part C: Benthic chlorophyll *a* criterion for rivers and streams; and
Part D: Eutrophication criteria for the Mississippi River pools and Lake Pepin.

IV.A. Multi-indicator eutrophication criteria for protection of aquatic life for rivers and streams (by ecoregion)

IV.A.1. Multi-indicator eutrophication criteria for rivers and streams

Minnesota's multi-indicator[2] eutrophication criteria for protection of aquatic life use designations for rivers and streams consist of a set of values for total phosphorus and four response indicators (sestonic chlorophyll *a*, diel DO flux, BOD_5 and pH), which are set forth at Minn. R. 7050.0222, Subps. 2, 3, and 4 for three nutrient ecoregions and (b) narrative provisions at Minn. R. 7050.0222, Subps. 2b, 3b, and 4b that define how the values in the tables apply in relation to each other. The tables and narrative provisions provide that eutrophication criteria are met in a water if 1) the TP concentration of that water exceeds the TP value but none of the concentrations of the response indicators exceeds any of the response variable values (*i.e.*, sestonic chlorophyll *a*, diel DO flux, BOD_5 and pH) or 2) if the TP concentration of the water does not exceed the TP value; and they are not met in a water if the TP concentration exceeds the TP value and the concentration of any of the response variables also exceeds the response variable value. In effect, Minnesota's eutrophication criteria, therefore, consist of four separate dual-pollutant criteria (TP+sestonic chlorophyll *a*, TP+diel DO flux, TP+BOD_5 and TP+pH). MPCA adopted unique dual-pollutant criteria for each of the specified "ecoregions" (North, Central or South). The following table (Table IV.1) is a compilation of the values for each of the three ecoregions:

Table IV.1. Minnesota's multi-indicator eutrophication criteria for rivers and streams

Ecoregion	TP (µg/L)	Chlorophyll *a* (µg/L)	Daily DO flux (mg/L)	BOD_5 (mg/L)	pH
North	50	7	3	1.5	CW: 6.5-8.5 WW: 6.5-9.0 (From MN WQS)
Central	100	18	3.5	2	
South	150	35	4.5	3	

[2]The terms "indicator" and "variable" have the same meaning in this document. "Indicator" generally is used in reference to the specific criteria adopted by Minnesota, and "variable" is used in reference to EPA's Stressor-response Guidance.

IV.A.2. How Minnesota derived its multi-indicator eutrophication criteria for rivers and streams

Since 1998, EPA has published several guidance documents summarizing and synthesizing the science related to development of nutrient criteria for protection of aquatic life designated uses. In those guidance documents, EPA describes several approaches that, based on EPA's review of the scientific literature, provide sound scientific rationale for development of nutrient criteria that are protective of aquatic life designated uses. It is important to note that EPA does not believe that there is only one, single approach that must be taken in developing nutrient criteria. A state's proper use of any one of EPA's recommended approaches or any other scientifically valid approach can satisfy the requirement of 40 CFR 131.11(a) that criteria must be based on "sound scientific rationale" and "protect the designated use." One of EPA's recommended approaches is the 2010 guidance document, entitled "Using Stressor-response Relationships to Derive Numeric Nutrient Criteria" ("Stressor-response Guidance"), available at http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/Using-Stressor-response-Relationships-to-Derive-Numeric-Nutrient-Criteria-PDF.pdf.

The Stressor-response Guidance sets forth a four-step process based on sound scientific rationale for developing nutrient criteria that are protective of aquatic life designated uses (pp. ix-x):

1. Step 1: "conceptual models representing known relationships between nitrogen (N) and phosphorus (P) concentrations, biological responses, and attainment of designated uses are developed for the study area."
2. Step 2: "data are assembled and initial exploratory analyses are performed. Variables are selected during this step that represent different concepts shown on the conceptual model, including variables that represent N and P concentrations, variables that represent responses that can be directly linked with designated uses, and variables that can potentially confound estimates of stressor-response relationships."
3. Step 3: "stressor-response relationships are estimated between N and P concentrations and the selected response variables, and criteria are derived from these relationships."
4. Step 4: "the accuracy and precision of estimated stressor-response relationships are evaluated and the analyses documented."

For the reasons described in EPA's 2010 Stressor-response Guidance, this four-step approach, if properly applied, provides a sound scientific rationale for developing nutrient criteria that are protective of aquatic life designated uses. In 2009, EPA's Office of Science and Technology (OST) requested that EPA's Science Advisory Board (SAB) review a draft of the Stressor-response Guidance to provide OST with independent scientific peer review and expert advice on scientific and technical aspects of the draft guidance. In its April 27, 2010, letter to EPA Administrator Lisa Jackson, the SAB indicated that "the stressor-response approach is a legitimate, scientifically based method for developing numeric nutrient criteria if the approach is appropriately applied (*i.e.*, not used in isolation but as part of a weight-of-evidence approach)."

As described in detail below, MPCA followed a process consistent with the four-step process set forth in EPA's Stressor-response Guidance to derive its eutrophication criteria for protection of aquatic life designated uses for rivers and streams. MPCA first developed a conceptual model to describe the way that increasing concentrations of nutrients (*i.e.*, eutrophication) affect aquatic ecosystems. MPCA identified chlorophyll *a*, diel DO flux, BOD_5, and diel maximum pH as indicators of primary producer community and ecosystem response, based on the conceptual model. MPCA then tested whether Minnesota's data exhibited the expected correlations predicted by the model. MPCA determined that, in Minnesota, TP correlates with these indicators and confirmed that increasing concentrations of phosphorus generally impact aquatic ecosystems in a manner consistent with its conceptual eutrophication model. With the exception of pH, which is already included in Minnesota's approved WQS as a criterion protective of aquatic life uses, MPCA then analyzed the relationship of each of the eutrophication indicators to selected measures of biological community health using quantile regression and changepoint analysis. This analysis identified statistically significant thresholds based on changes in direct biological measures of aquatic life use support. MPCA analyzed the data and relationships in a regional context.

These preliminary biologically-based thresholds were then compared to concentrations measured in minimally-disturbed reference sites in Minnesota, values drawn from the relevant scientific literature, and values derived through simple linear and serial regression analyses. Final criteria values were set at levels to protect aquatic life uses and prevent significant degradation from expected conditions.

IV.A.3. Minnesota's multi-indicator eutrophication criteria for rivers and streams are based on sound scientific rationale and protective of designated aquatic life uses

As described below, in developing its multi-indicator eutrophication criteria for rivers and streams, MPCA had sound scientific rationale for how it applied each of the four steps of the process set forth in EPA's Stressor-response Guidance for developing nutrient criteria that are protective of aquatic life designated uses.

IV.A.3.a. Step 1: Conceptual model development

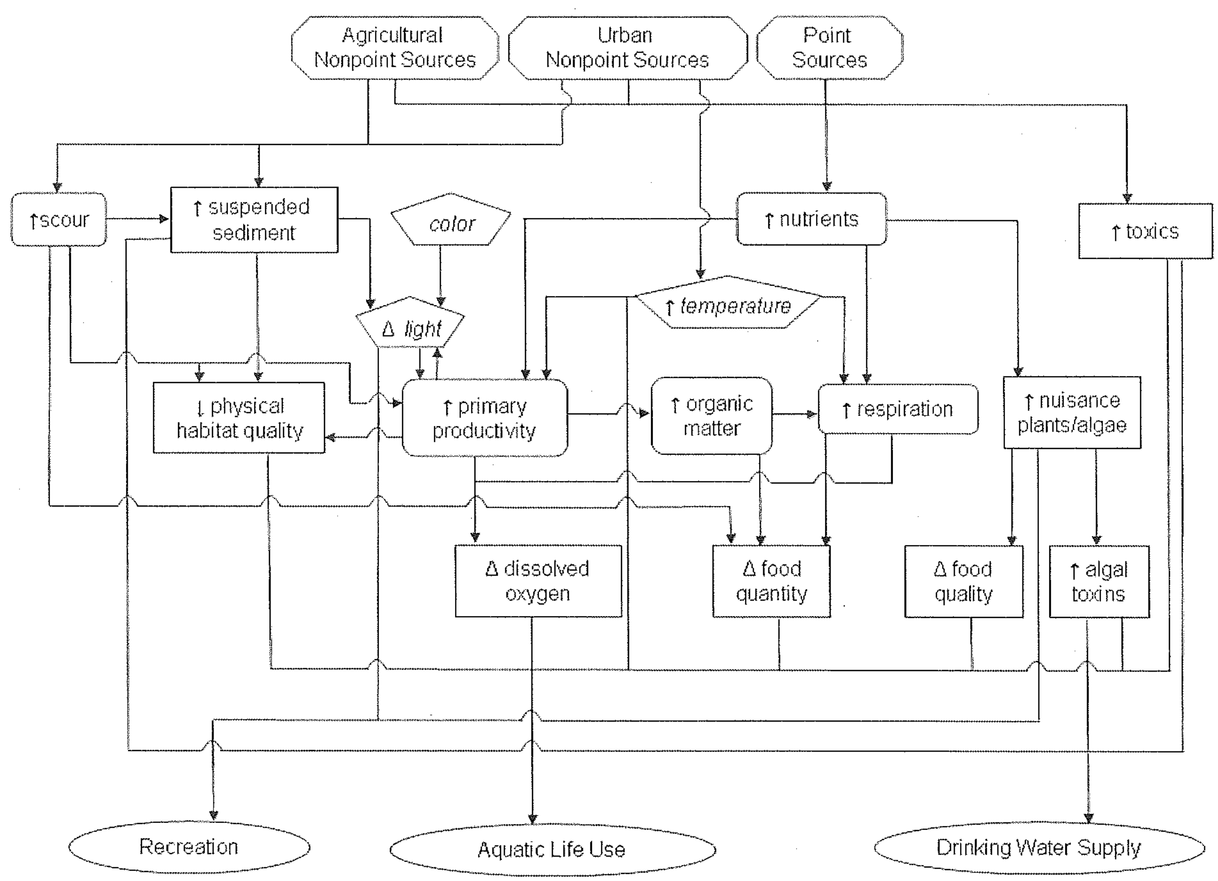
As described above, the first step in the four-step process for development of nutrient criteria protective of aquatic life uses set forth in the Stressor-response Guidance is development of a conceptual model. Conceptual models are important tools in deriving nutrient criteria because they depict accepted scientific knowledge and, accordingly, guide indicator variable selection and subsequent causal and indicator threshold identification. EPA has published conceptual models of nutrient enrichment, including conceptual models for both lakes and streams in its Stressor-response Guidance. EPA's conceptual models are based on an extensive review of the relevant scientific literature. The literature review is summarized on page 5 of the Stressor-response Guidance, although additional sources are cited in subsequent discussion in the guidance:

> The causal pathways that lead from human activities to excess N and P to impacts on designated uses in lakes and streams are well established in the scientific literature (*e.g.*, streams: Stockner and Shortreed 1976, Stockner and Shortreed 1978, Elwood *et al.* 1981, Horner *et al.* 1983, Bothwell 1985, Peterson *et al.* 1985, Moss *et al.* 1989, Dodds and Gudder 1992, Rosemond *et al.* 1993, Bowling and Baker 1996, Bourassa and Cattaneo

1998, Francoeur 2001, Biggs 2000, Rosemond *et al.* 2001, Rosemond *et al.* 2002, Slavik *et al.* 2004, Cross *et al.* 2006, Mulholland and Webster 2010; lakes: Vollenweider 1968, NAS 1969, Schindler *et al.* 1973, Schindler 1974, Vollenweider 1976, Carlson 1977, Paerl 1988, Elser *et al.* 1990, Smith *et al.* 1999, Downing *et al.* 2001, Smith *et al.* 2006, Elser *et al.* 2007).

The conceptual model in the Stressor-response Guidance for streams (reproduced as Figure IV.1, below) identifies primary productivity (depicted as sestonic chlorophyll *a* in MPCA's conceptual model) and microbial activity (depicted as increased respiration in EPA's conceptual model and an increase in microbes in MPCA's conceptual model) as the primary routes by which nutrient enrichment impacts streams.

Figure IV.1. EPA's conceptual model for streams (EPA Stressor-response Guidance, p. 13)



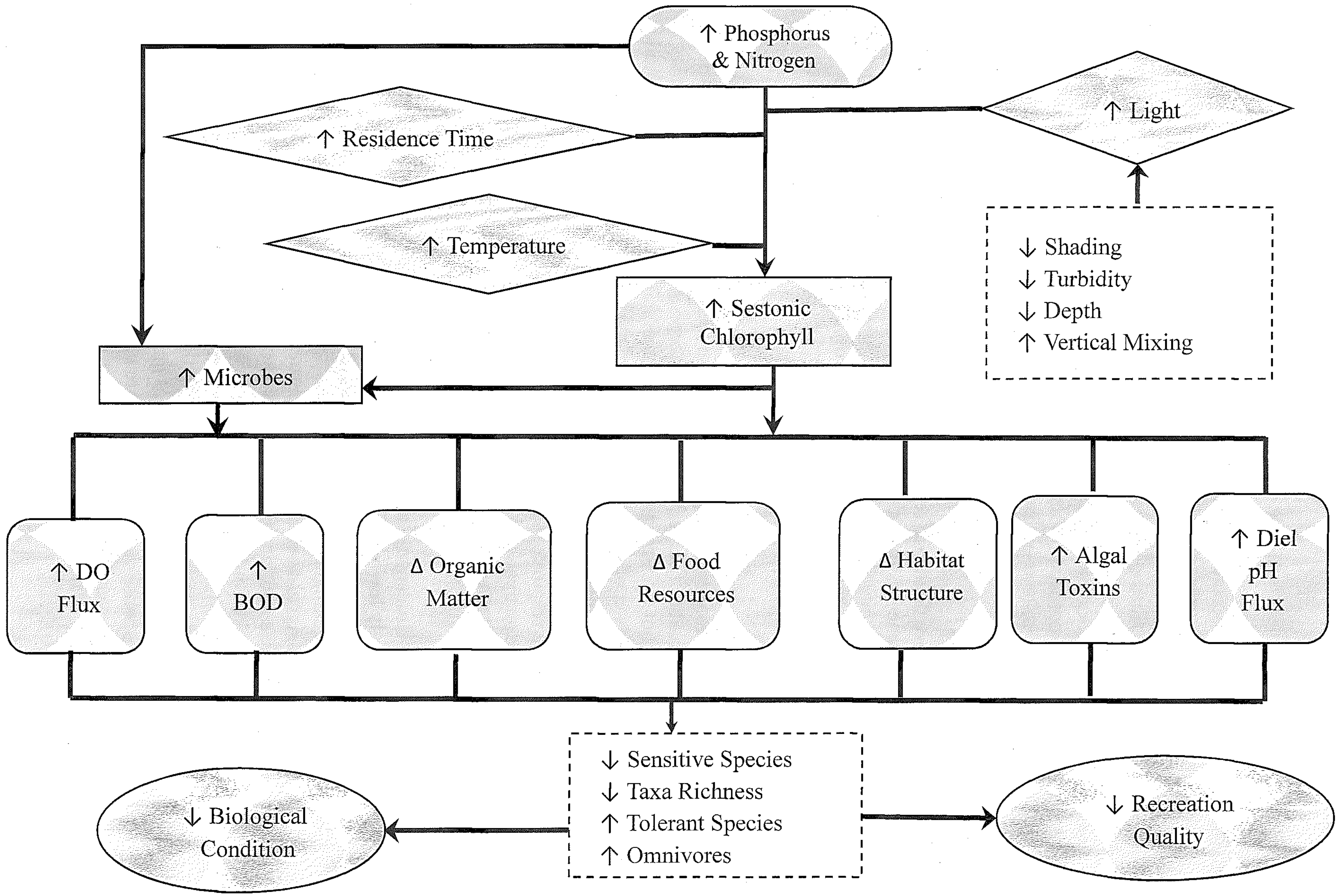
In particular, the model indicates that increases in primary productivity subsequently alter herbivore assemblages, food resources, and physical habitat, and that the combined effect of increased organic matter (from increased primary production) and increased microbial activity increases respiration and consumes oxygen:

> One of the more important pathways by which nutrient enrichment affects designated uses in streams is by increasing primary productivity. Increased N and P also alter the composition of the primary producer assemblage (Rosemond *et al.* 1993, Slavik *et al* 2004), including the amount and ratio of edible and non-edible forms, which alters herbivore assemblages (Feminella and Hawkins 1995, Hillebrand 2002). Food quantity may be increased by excess organic matter (from increased primary production), which also favors some consumers over others and changes the natural composition of taxa evolved to compete for natural amounts of different food types (Hawkins *et al.* 1982, Fuller *et al.* 1986, Wallace and Gurtz 1986). Excess primary production also alters physical habitat. For example, excess filamentous algae alters the normal physical habitat, interfering with movement, affecting visual predation, and blocking access to feeding and reproductive habitat for some organisms (Slavik *et al.* 2004), while favoring others (Dudley *et al.* 1986)...Nitrogen/phosphorus pollution also increases microbial production (fungi and bacteria)...The combined effect of increased organic matter (from increased primary productivity) and increased microbial activity is an increase in heterotrophic respiration, which consumes dissolved oxygen (Allan and Castillo 2007). Dissolved oxygen availability is critical to invertebrate and vertebrate taxa, and different species vary in their requirements for dissolved oxygen. As a result, changes in oxygen concentrations alter aquatic communities (*e.g.*, Miranda *et al.* 2000, Caraco *et al.* 2006). (EPA Stressor-response Guidance, pp. 11-12)

MPCA's conceptual model (reproduced as Figure IV.2, below), from the Minnesota Nutrient Criteria Development for Rivers, 2013 (Eutrophication Technical Support Document (Eutrophication TSD)), is markedly similar to EPA's conceptual method in the following key aspects: 1) increased concentrations of nutrients in aquatic systems can culminate in adverse impacts to biota due to changes in the chemical habitat (DO, pH) and disruption of the food web, 2) increases in sestonic algal and microbes are the initial points in the eutrophication process at which increased concentrations of nutrients move into the biota and trigger disturbances throughout the aquatic ecosystem, 3) chlorophyll *a*, daily DO flux, pH, and BOD_5 are key indicators of the initial response of the primary producer and microbial communities, and 4) changes in the plant and bacterial production can influence aquatic animals through alteration of the quantity and quality of their food resources, as well as through alteration of the water chemistry regime (*i.e.*, increased DO and pH flux). Hence, MPCA's conceptual model is based on sound scientific rationale because it is consistent with the conceptual model from EPA's Stressor-response Guidance. It should be noted that all of the sources cited by MPCA in the Eutrophication TSD, pages 3-6 and 89, pertaining to MPCA's development of its conceptual model are from published scientific journals. Also, many of those sources, as well as additional published articles by many of the authors cited by MPCA, are cited by EPA in the Stressor-response Guidance, pages 5-14.

Additionally, as observed in the following section (Step 2: Candidate variable selection), the observed correlations between model components derived from Minnesota field data are consistent with the predictions of the model and thereby support the conclusion that the model's application for nutrient enrichment in Minnesota is based on sound scientific rationale.

Figure IV.2. MPCA's conceptual model of nutrient enrichment (Eutrophication TSD, p. 4)



IV.A.3.b. Step 2: Exploratory data analysis

As described above, the second step in the four-step process for development of nutrient criteria protective of aquatic life uses set forth in the Stressor-response Guidance is to assemble data and perform initial exploratory analyses of possible stressor-response relationships. The Stressor-response Guidance describes exploratory data analysis as "an approach to examine and visualize data to understand likely relationships, indicate appropriate statistical modeling approaches, and assess the basis for statistical modeling assumptions (Tukey 1977)." EPA's Stressor-response Guidance provides an approach for using exploratory analysis in nutrient criteria development. In particular, EPA's Stressor-response Guidance makes recommendations on selecting variables and use of graphical and statistical tools for exploratory analysis of nutrient stressor-response relationships.

EPA's Stressor-response Guidance recommends that the variables used for exploratory data analysis 1) represent concepts from the conceptual model and 2) reflect multiple pathways for linking the nutrients and biological response. EPA's Stressor-response Guidance provides examples of variables that typically are found in eutrophication conceptual models. For streams, such variables include nutrients, chlorophyll *a*, BOD, DO concentration profiles, and biological indicators. (EPA Stressor-response Guidance, p. 17).

> In general, while assembling data, one tries to identify variables that represent each of the concepts in the conceptual model diagram that has been modified to represent the region's waterbodies (Table 3-1). Certain concepts shown on the diagram may not have available data, but the structure of the conceptual model diagram can help guide the selection of a subset of concepts that, if included in the analysis, will best improve the accuracy of the estimated stressor-response relationships. More specifically, the conceptual model diagram can be used to identify alternate pathways linking the nutrient variable and the response variable. Then, inclusion of a variable from each of these pathways in the analysis can help ensure that estimated stressor-response relationships are accurate (Morgan and Winship 2007, Pearl 2009). (EPA Stressor-response Guidance, p. 15)

The Stressor-response Guidance also recommends that variables used for exploratory data analysis exhibit relatively low variability to biological response:

> Other factors one might consider in selecting response variables include the inherent variability and signal-to-noise ratio of a particular measurement. An estimate of a stressor-response relationship for a highly variable measurement (*e.g.*, abundance of a particular species) would be imprecise, which affects one's ability to specify appropriate criteria (see Section 5.2). US EPA has historically recommended particular variables, where appropriate, for criteria (US EPA 2000a, 2000b, 2001). These variables include the "primary causal variables", which are total nitrogen (TN) and total phosphorus (TP), and the "primary response variables", which are chlorophyll a (chl *a*) and clarity. In some cases, selecting several different response variables and conducting stressor-response analyses for each of them may provide useful insights. (EPA Stressor-response Guidance, p. 16)

Additionally, candidate biological response variables should represent the most sensitive designated use and should identify an appropriate measure of effect:

> Selecting appropriate response variables requires further consideration. First, one should identify the designated use that is likely to be sensitive to increased N and P (*e.g.*, aquatic life use support). Second, analysts should select an assessment endpoint that represents the designated use (*e.g.*, health of the benthic macroinvertebrate community). Third, analysts should identify an appropriate measure of effect (US EPA 1998) for the selected assessment endpoint (*e.g.*, a multimetric index value). In general, the most appropriate response variable both measures whether the designated use of the waterbody is supported and responds to changes in N and P concentration. (EPA Stressor-response Guidance, p. 16)

Further, the Stressor-response Guidance recommends the use of both quantitative and graphical statistical techniques, including correlation analyses and scatterplots:

> Correlation analysis is a method for measuring the degree to which the values of two variables change together across different samples. The correlation coefficient quantifies the strength of the relationship between two variables and is a unitless number that varies from -1 to +1. The magnitude of the correlation coefficient is the standardized degree of association between the two variables. The sign is the direction of the association, which can be positive or negative. A coefficient near 0 indicates that the two variables are not related. A negative coefficient indicates that as the value of one variable increases, the other decreases. A positive coefficient indicates that as the value of one variable increases the other also increases. Larger absolute values of coefficients indicate stronger associations; however, in some cases small coefficients may be due to a nonlinear relationship.
>
> Two types of correlations are used most frequently. Pearson's product-moment correlation coefficient, r, measures the degree of linear association between two variables. Spearman's rank-order correlation coefficient (ρ) uses the ranks of the data, relaxing the linearity assumption of r, and can provide a more robust estimate of the degree to which two variables are monotonically associated even if the relationship is non-linear. (EPA Stressor-response Guidance, pp. 23-24)
>
> Examining scatter plots (Section 3.3.2.2) supplements the insights provided by correlation coefficients...Scatter plots are used to visualize the relationship between two variables. In addition to indicating how strongly two variables are related, scatter plots can indicate whether a straight line or other functional form can reasonably represent an observed relationship. (EPA Stressor-response Guidance, p. 24)

MPCA conducted exploratory data analysis as a step in its eutrophication criteria development and, as described below, its use of exploratory data analysis is consistent with the recommendations in EPA's Stressor-response Guidance. A detailed description and results of MPCA's exploratory data analysis is provided below, in this section. In summary:

- MPCA selected eutrophication indicators (*i.e.*, TP, chlorophyll *a*, DO, and BOD_5) that 1) reflect the concepts or ecological processes of its conceptual model, 2) consider multiple pathways linking TP and biological response and 3) are significantly correlated to ecological response, determined through measures of aquatic community health.
- The biological response metrics that MPCA evaluated (*i.e.*, measures of aquatic community health) address the most sensitive designated use of Minnesota rivers and streams (*i.e.*, aquatic community health). By virtue of a diverse array of measures (*i.e.*, 8 measures of fish community health and 6 measures of invertebrate community health), the set of biological response metrics reflects aquatic life protection.
- MPCA used both graphical tools (*i.e.*, scatter plots and histograms) and basic quantitative tools (*i.e.*, Pearson's correlation and Spearman's rank-order correlations) in conducting the exploratory data analysis.

Based on its conceptual model, MPCA identified candidate indicator variables (*i.e.*, TP, sestonic chlorophyll *a*, diel DO flux, and BOD_5) for exploratory data analysis. MPCA conducted simple linear regressions (SLR) and Loess regressions on data from MPCA's Rivers Nutrient Study (RNS) and Minnesota data from EPA's STORET, as presented on Pages 44-52 of MPCA's Eutrophication TSD. Establishing that these relationships are consistent with the relationships predicted by the conceptual model validates the model and the use of the indicator variables identified by MPCA as components of its eutrophication criteria and criteria development. Based on these analyses, MPCA determined that the relationships among TP, chlorophyll *a*, diel DO flux, and BOD_5, compiled in Table IV.2 below, support both development of eutrophication criteria for rivers and streams and construction of the standard to incorporate both enrichment and response indicators in a single standard.

Table IV.2. Coefficients of determination between components of Minnesota's eutrophication criteria for rivers and streams. (Eutrophication TSD, pp. 44-52)

	Chlorophyll *a*	**BOD**	**Diel DO flux**
TP	0.81, RNS, log/log LSR	0.58, RNS, Loess	0.52, RNS, LSR
	0.58, RNS, Loess		
	0.42, STORET, Loess	0.54, STORET, Loess	
Chlorophyll *a*		0.93, RNS, LSR	0.66, RNS, LSR
		0.85, STORET, Loess	
BOD			---

Specifically, MPCA concluded that the data support the hypothesized mechanism for eutrophication of Minnesota rivers and streams contained in the conceptual model. That is, increased phosphorus concentrations leads to increases in autotrophic (plant) biomass that is detectable as increased sestonic chlorophyll *a* and heterotrophic (bacterial) biomass and the biological activity of the increased autotroph and heterotroph biomass results in detectable changes in the water column diel DO flux, BOD_5, and diel maximum pH at the site.

After identifying the eutrophication indicators, as described above, MPCA selected biological metrics used by Minnesota to assess aquatic community condition to relate the eutrophication indicators to aquatic life use protection, as described on page 30 of the Eutrophication TSD:

> The selection of a subset of metrics was made using several methods. Spearman rank correlations were examined using the River Nutrient dataset to identify metrics with a strong relationship between the total phosphorus and biological metrics (see Table 16). Some of the metrics that were significantly correlated were eliminated due to the redundancy of metrics and the relevance of the metrics to nutrient enrichment (*i.e.,* can a mechanism between nutrient enrichment and the response in that metric be identified). Eight metrics were selected for fish and six metrics for macroinvertebrates (Table 11).

From the Spearman rank analysis, MPCA determined that "strong correlations are evident for many of the biological metrics (Eutrophication TSD, p. 63)." MPCA observed that, "the more prominent biological measures, as shown by high Rs [Spearman rank coefficients], are as follows: number of macroinvertebrate taxa, number of EPT taxa, fish IBI, # of sensitive fish taxa, percent sensitive fish, simple lithophils (both as # of taxa and as a percent of overall fish community), and relative abundance of amphipods." The results of the Spearman rank correlations are found in Table 16 of the Eutrophication TSD (p. 64). MPCA subsequently sorted out measures of aquatic community health that are redundant based on professional field experience in Minnesota. MPCA then used scatterplots to visually examine the range of eutrophication indicator concentrations associated with where the shifts in the biological metrics occur. (Eutrophication TSD, pages 65-70)

The final 14 metrics that were selected for the piecewise quantile regressions and changepoint analysis from the Spearman rank analysis and the scatterplots are reproduced in Table IV.3, below, from Table 11, page 28 of the Eutrophication TSD:

Table IV.3. Fish and macroinvertebrate metrics used to develop concentration thresholds

Fish Metrics	**Invertebrate Metrics**
% Sensitive	Total Taxa Richness
% Darter	Collector-filterer Taxa Richness
% Simple Lithophils	Collector-gatherer Taxa Richness
% Tolerant	EPT Taxa Richness
% Insect	Intolerant Taxa Richness
% Piscivore	% Tolerant
Taxa Richness	
% Intolerant	

The Eutrophication TSD and SONAR provided by MPCA speak at length to MPCA's identification of response indicators based on their placement in the conceptual model as the initial biological responses to enrichment. Consistent with this approach, MPCA selected TP as an indicator of enrichment (termed "primary causal variable" in the Stressor-response Guidance), and sestonic chlorophyll *a*, diel DO flux, diel maximum pH, and BOD_5 as indicators of response (termed "primary response variables" in the Stressor-response Guidance). MPCA derived coefficients of determination that verify that the relationships hypothesized by the conceptual model are supported by the field data. Because the individual variables of the eutrophication criteria are related to each other, there is sound scientific rationale to conclude that controlling TP will prevent changes in autotroph and heterotroph communities that lead to changes in water quality and trophic structures that can result in impairment of aquatic life uses of Minnesota rivers and streams. The regression analyses described above support MPCA's selection of response indicators necessary to protect aquatic life and the determination that aquatic life uses are not protected when TP and one or more response variable thresholds are exceeded. The eutrophication indicators selected by MPCA, including total phosphorus, sestonic and benthic chlorophyll *a*, daily DO flux, pH, and BOD, are also among those recommended for use for nutrient criteria for rivers and streams by attendees of EPA's 2013 expert workshop on nutrient indicators in streams. This workshop brought together a group of scientific experts invited by EPA to identify appropriate indicators for use in nutrient criteria development for rivers and streams. (Proceedings from U.S. EPA expert workshop: nutrient enrichment indicators in streams, September, 2014)

MPCA's use of Spearman rank-order correlation to identify biological metrics responsive to the eutrophication indicators that comprise Minnesota's eutrophication criteria is supported by EPA's Stressor-response Guidance, which identifies Spearman rank-order correlations as a scientifically valid and widely-used analysis tool for determining the degree by which two variables are correlated (p. 23):

> Correlation analysis is a method for measuring the degree to which the values of two variables change together across different samples. The correlation coefficient quantifies the strength of the relationship between two variables and is a unitless number that varies from -1 to +1. The magnitude of the correlation coefficient is the standardized degree of association between the two variables. The sign is the direction of the association, which can be positive or negative. A coefficient near 0 indicates that the two variables are not related. A negative coefficient indicates that as the value of one variable increases, the other decreases. A positive coefficient indicates that as the value of one variable increases the other also increases. Larger absolute values of coefficients indicate stronger associations; however, in some cases small coefficients may be due to a nonlinear relationship.
>
> Two types of correlations are used most frequently. Pearson's product-moment correlation coefficient, r, measures the degree of linear association between two variables. Spearman's rank-order correlation coefficient (ρ) uses the ranks of the data, relaxing the linearity assumption of r, and can provide a more robust estimate of the degree to which two variables are monotonically associated even if the relationship is non-linear.

Additionally, EPA's Stressor-response Guidance supports MPCA's use of scatter plots. Specifically, the Stressor-response Guidance indicates that scatter plots are useful in determining the strength of the relationship of two variables as well as whether the relationship is best described by a line vs. another functional form (p. 24):

Scatter plots are used to visualize the relationship between two variables. In addition to indicating how strongly two variables are related, scatter plots can indicate whether a straight line or other functional form can reasonably represent an observed relationship.

An example scatter plot of TN versus a multimetric macroinvertebrate index of biological condition (MMI) is shown in Figure 3-6. Decreases in MMI are associated with increases in TN concentration, but the variability in sample values about the mean relationship is large.

A comment was raised during Minnesota's public review period regarding whether BOD_5 and diel DO flux were sufficiently related to TP to be included as indicators in Minnesota's eutrophication criteria. MPCA responded that its approach of using combinations of causal and response indicators to assess rivers for impairment ensures that rivers exhibiting only elevated chlorophyll *a*, BOD_5, or diel DO flux without elevated phosphorus would not be assessed as impaired without further analysis. MPCA recognized that all of the response indicators (*i.e.*, chlorophyll *a*, diel DO flux, and BOD_5) can be influenced by factors other than phosphorus. Accordingly, MPCA developed a structure for its eutrophication criteria so that both TP and a response indicator (*e.g.*, BOD_5) must be exceeded to conclude that aquatic life uses would not be protected. MPCA agreed in its response to the comment that BOD_5 cannot be used as a stand-alone criterion of nutrient enrichment based on the very reason raised by the commenter, that factors other than phosphorus can increase BOD_5 concentrations. However, for the reasons explained in MPCA's response to this comment, MPCA had a sound scientific rationale to conclude that high BOD_5 concentrations and high diel DO flux result from phosphorus enrichment, as supported by the coefficients of determination found in the MPCA data sets (Eutrophication TSD, pp 44-54):

TP *vs*. BOD_5, $R^2 = 0.58$ (RNS data, Loess regression)
TP *vs*. BOD_5, $R^2 = 0.54$ (STORET data, Loess regression)
TP *vs*. daily DO flux, $R^2 = 0.52$ (RNS data, simple linear regression)

MPCA's decision to include BOD in the multi-indicator eutrophication criteria is consistent with the conclusion of the proceedings from the U.S. EPA expert workshop: nutrient enrichment indicators in streams, September, 2014, which identifies BOD as an indicator of eutrophication's impacts on ecosystem function. Additionally, diel DO flux and especially BOD_5 are related to chlorophyll *a*, meaning it is unlikely that a response in diel DO flux or especially BOD_5 would occur without the presence of a similar response in chlorophyll *a*.

Chlorophyll *a vs*. BOD_5, $R^2 = 0.93$ (RNS data, simple linear regression)
Chlorophyll *a vs*. BOD_5, $R^2 = 0.85$ (STORET data, Loess regression)
Chlorophyll *a vs*. daily DO flux, $R^2 = 0.66$ (RNS data, simple linear regression)

In conclusion, MPCA's approach to exploratory data analysis is based on sound scientific rationale, as it uses the recommendations and statistical tools from EPA's Stressor-response Guidance. In particular, given the conceptual model, the correlations between TP and diel DO flux and between TP and BOD_5, and the correlations among the indicator variables (*i.e.*, chlorophyll *a*, diel DO flux, and BOD_5), both MPCA's selection of TP, chlorophyll *a*, BOD_5 and diel DO flux as criteria components and MPCA's determination that TP and indicator variables must both be exceeded to demonstrate that aquatic life uses are not protected has a sound scientific rationale. Further, MPCA had a sound scientific rationale for selecting TP and pH as criteria components since increased primary production and bacterial activity may result in variation in pH, consistent with MPCA's conceptual model.

IV.A.3.c. Step 3: Stressor-response relationship evaluation and criteria derivation

As described above, the third step in the four-step process for development of nutrient criteria protective of aquatic life uses set forth in the Stressor-response Guidance is further, in-depth analysis of stressor-response relationships and criteria derivation.

IV.A.3.c.i. Classification of Waterbodies

As an initial step in analyzing stressor-response data, the Stressor-response Guidance recommends the classification of waterbodies by ecoregion to account for other environmental variables that may influence relationships between a nutrient and a response variable:

> In the first step of the analysis, *classification*, the analyst attempts to control for the possible effects of other environmental variables by identifying classes of waterbodies that have similar characteristics and are expected to have similar stressor-response relationships. Classifications for a stressor-response analysis are typically based on statistical analysis; however, existing classes can be used as a starting point. The most widely used existing classifications for analyses of nutrient data are the fourteen national nutrient ecoregions (Omernik *et al.* 2000, USEPA 2000a). These ecoregions were designated based on similar climate, topography, regional geology and soils, biogeography, and broad land use patterns. (EPA Stressor-response Guidance, p. 32)

Additionally, EPA has published extensively on ecoregional classification of waterbodies for nutrient criteria development. In particular, EPA published national ecoregional-based water quality criteria recommendations in 2000 for rivers and streams. EPA's 2000 publication was based on the sound scientific rationale that nutrient background concentrations vary on an ecoregional basis:

> In 1995, EPA gathered a set of national experts and asked the experts how to best deal with the national nutrient problem. The experts recommended that the Agency not develop single criteria values for phosphorus or nitrogen applicable to all water bodies and regions of the country. Rather, the experts recommended that EPA put a premium on regionalization, develop guidance (assessment tools and control measures) for specific waterbodies and ecological regions across the country, and use reference conditions (conditions that reflect pristine or minimally impacted waters) as a basis for developing nutrient criteria." (EPA Ecoregional Criteria for Rivers and Streams, VI, 2000, p. 1)
>
> Because some parts of the country have naturally higher soil and parent material enrichment, and different precipitation regimes, the application of the criterion development process has to be adjusted by region. Therefore, an ecoregional approach

was chosen to develop nutrient criteria appropriate to each of the different geographical and climatological areas of the country." (EPA Ecoregional Criteria for Rivers and Streams, VI, 2000, VI, 2000, p. 3)

EPA's 2000 ecoregional criteria recommendations used previous work from the scientific literature and local state, federal, and academic experts on eutrophication, including Steve Heiskary, a primary author of the supporting documentation for MPCA's eutrophication criteria, as observed in the forward of the 2000 guidance for the Cornbelt and Northern Great Plains ecoregion:

> The authors thankfully acknowledge the contributions of the following State and Federal reviewers: EPA Regions 5, 7, and 8; the States of South Dakota, North Dakota, Nebraska, Minnesota, Iowa, Illinois, Wisconsin, Indiana, Michigan and Ohio; the Tribes within Ecoregion VI; EPA Headquarters personnel from the Office of Wetlands, Oceans and Watersheds, Office of Wastewater Management, Office of General Counsel, Office of Research and Development, and the Office of Science and Technology. EPA also acknowledges the external peer review efforts of Eugene Welch (University of Washington), Robert Carlson (Kent State University), Steve Heiskary (Minnesota Pollution Control Agency), Greg Denton and Sherry Wang (Tennessee Department of Environment and Conservation), and Gerhard Kuhn (U.S. Geological Survey). (EPA Ecoregional Criteria for Rivers and Streams, VI, 2000, p. 1, p. viii)

MPCA confirmed that background concentrations of TP varied by ecoregion in Minnesota as did biological response to nutrients. MPCA subsequently divided the state into three nutrient ecoregions, largely along the recommendations of EPA's national recommended nutrient criteria, and conducted the statistical analyses for each ecoregion separately in order to determine defensible eutrophication indicator values. The resulting criteria reflect the differences in expected phosphorus and response variable concentrations across Minnesota. Page 1 of the Eutrophication TSD provides the rationale for why MPCA determined that background concentrations of TP vary across the state:

> Consistent with EPA guidance, data and relationships were analyzed in a regional context. Threshold concentrations ranges were placed in context with ecoregion-based frequency distributions compiled by MPCA for representative, minimally-impacted streams (McCollor & Heiskary 1993), a more recent compilation of stream TP data from STORET (period from 1996-2012), and IQ ranges from USEPA criteria manuals (USEPA 2000b, a, 2001). These data distributions reflect distinct regional differences in stream TP, BOD5, and other variables. This work combined with previous analysis of Minnesota's ecoregional patterns resulted in defining three "River Nutrient Regions (RNR)" for criteria development.

Page 87 of the Eutrophication TSD provides the findings of the Additive Quantile Regression Smoothing (AQRS) and changepoint analyses regarding whether the biological community response to nutrients varies by ecoregion in Minnesota:

> Examination of the threshold concentrations derived from both fish and macroinvertebrate data reveals a number of apparent patterns. There was a gradient of increasing threshold concentrations from north to south. The north-south criteria gradient may be due to differences in the biological communities between regions and may also reflect differences in land use, soils, and geomorphic patterns across the state (*i.e.,* ecoregions). This suggests that statewide nutrient criteria may not be appropriate due to the range of criteria developed using quantile regression and changepoint analyses across the state (Table 20), and that these criteria should be regionalized. Regional patterns in modern-day water quality (*e.g.*, TP and BOD; Table 20 and Appendix I) and estimated background TP (Smith *et al.* 2003) further reinforce regional patterns and differences between threshold concentrations from wadeable and nonwadeable streams were not consistent across regions. The causes of this pattern are not clear, but it is possible that natural differences in nutrient concentrations are partially responsible for differences in the native species pools present in these regions. For example, southern fauna are better suited to more enriched conditions than are the northern fauna. Regardless of the cause of the pattern, these results suggest that regionalized nutrient criteria are appropriate. There was little difference between threshold concentrations developed for the two taxonomic groups *(i.e.*, fish and macroinvertebrates), suggesting that both taxonomic groups respond to nutrients and related stressors and can be used together to develop nutrient criteria. Observed thresholds from basic regressions (Figure 37) and ranges for phosphorus criteria developed from quantile regression and changepoint analysis, using fishes and macroinvertebrates, were within or near the range of thresholds reported in the literature (Table 20b).

MPCA provides details regarding how biological response to TP and BOD_5 varies by ecoregion (pp. 74-75 of the Eutrophication TSD):

> No threshold concentrations could be determined for BOD_5 in the northern streams due to a limited stressor range in this region (Figure 47). There was a significant difference between BOD_5 threshold concentrations for the central and southern stream classes based on Mann-Whitney Rank Sum test (data failed normality test) f ($P = 0.0399$) (SigmaPlot ver. 11; Systat Software 2008). This suggests that different thresholds are appropriate for these two regions.
>
> A Kruskal-Wallis Analysis of Variance (ANOVA) on Ranks was performed due to non-normality to test for differences in the total phosphorus threshold concentrations from different regions and river sizes (SigmaPlot ver. 11; Systat Software 2008). A significant difference ($P = <0.0001$) between the mean threshold concentrations was identified for the difference [*sic*] regions and river sizes…The most obvious differences were among the regional total phosphorus threshold concentrations with criteria values increasing from north to south… The threshold concentrations for the north region was significantly different ($P = <0.0001$) from the central and southern regions (Figure 48b). This suggests that regionalizing criteria is justified.

MPCA's determination that background phosphorus and response thresholds vary and that ecoregional criteria are appropriate across Minnesota is based on sound scientific rationale. It is reasonable to conclude that background phosphorus concentrations will decrease across the transition from fertile prairie in the southwest to unfertile rocky soil in the northeast. Unfertile, rocky soil typically results in lower levels of phosphorus leachate and flow into surface waters. Additionally, the scientific literature describes that background phosphorus and response thresholds vary significantly between regions in the United States (McCollor and Heiskary (1993), Rohm *et al.* 2002, Smith *et al.* 2003, and Wickham *et al.* 2005). Further, MPCA's approach for waterbody classification is consistent with the sound scientific rationale set forth in EPA guidance. Consequently, MPCA's ecoregional approach to criteria derivation is based on sound scientific rationale.

IV.A.3.c.ii. Criteria derivation

EPA's Stressor-response Guidance identifies statistical tools that are used in the science community to determine if stressor-response relationships exhibit statistically-significant thresholds. Those statistical tools are described on pages 32-34 and pages 49-55 of the Stressor-response Guidance. The recommended tools include simple linear regression, quantile regression, non-parametric regression curves (*i.e.*, "smoothing" techniques), and changepoint analysis. As discussed below, MPCA utilized these tools in deriving its eutrophication criteria.

Derivation of candidate thresholds. Based on the biological metrics identified above, MPCA derived a set of candidate biologically-based eutrophication indicator thresholds for TP, chlorophyll *a*, diel DO flux, and BOD_5 using piecewise quantile regressions and changepoint analysis. That is, MPCA identified candidate thresholds for each pairing of indicator variable and measure of aquatic community health (*e.g.*, TP *vs.* % sensitive fish), thereby producing a "candidate" threshold. This resulted in a potential of up to 28 candidate thresholds for each indicator variable (*i.e.,* 14 measures of measures of aquatic community health multiplied by 2 analysis tools). The candidate thresholds determined to be statistically significant for each indicator variable were then pooled, and the 25th percentile threshold value was selected as the final threshold concentration for the indicator. MPCA selected the 25th percentile because the central tendency selection may result in under-protection for approximately half of the metrics:

> The threshold concentrations were developed from different biological metrics which were selected because they were most sensitive to eutrophication. However, depending on the metric and biological group they have different responses to nutrients and stressors. As a result, the 25th percentile of these values [is] more relevant to the development of protective aquatic life criteria. A mean or median statistic would be under protective because the concentration threshold would be exceeded for approximately half of the biological metrics. Stevenson *et al.* (2008) states that: "Setting criteria below thresholds in responses demonstrating assimilative capacity provides a margin of safety to protect valued attributes". This safety factor is incorporated into this line of evidence by using the 25th percentile of threshold concentrations for each dataset. The combination of this more protective statistic and the use of sensitive metrics resulted in a line of evidence that is supportive of the CWA interim goal and Minnesota's aquatic life use goals. (Eutrophication TSD, p. 74)

Not all of the statistical analyses yielded usable threshold concentrations. MPCA cited the following reasons for not including a particular candidate threshold (Eutrophication TSD, p. 73):

- The metric did not respond to the stressor or responded in a manner contrary to the predicted response;
- AQRS fit failed F-test; and
- Threshold concentration failed significance test (chi-squared or Fisher Exact Test).

Candidate thresholds were retained only from those pairings in which the piecewise quantile regressions or changepoint analysis demonstrated a statistically significant relationship. Statistical significance was demonstrated in the piecewise quantile regressions through a Fisher's F-test and in the changepoint analysis through a chi-squared test. Additionally, MPCA noted that the effective use of piecewise additive quantile regression and changepoint analyses required datasets of sufficient size and accordingly developed statewide but not ecoregional thresholds for chlorophyll *a* and diel DO flux. A summary of statistics for the candidate thresholds is found on page 73 of the Eutrophication TSD.

In deriving the candidate biologically-based thresholds, MPCA used analysis techniques that are more advanced than simple linear regressions, namely quantile regression and changepoint analyses, which are well-suited to the wedge-shaped scatter plots observed in MPCA's biological data set. MPCA's rationale and protocol for using piecewise quantile regression and changepoint analysis to derive candidate thresholds is explained on page 30 of the Eutrophication TSD:

> A number of patterns can be observed between nutrients and the biological metrics (Brenden *et al.* 2008) although the relationship between biology and nutrients is often wedge shaped (Wang *et al.* 2007). In the Minnesota datasets used for this study, a distinct wedge with breakpoint(s) (Figures 10a, b and c) was most commonly observed. The "upper plateau" (see Figures 10a and c) occurred at generally low levels of nutrients or stressors and was characterized by high variability in the biological metric. The steep portion of the wedge occurred at moderate levels of the nutrient or stressor and indicated that a threshold had been crossed and that biological condition was declining. At higher levels of nutrients or stressors there was often a lower breakpoint that corresponded to low biological metric scores indicating that the response variable had largely reached bottom and was not declining or declining at a much slower rate (see Figures 10a and b). Additive quantile regression smoothing and changepoint analyses were both effective with this type of dataset. The fit of the quantile regression and the ability of the changepoint analysis to identify thresholds were assessed and analyses with a poor fit or those not identifying relevant thresholds were omitted. For some datasets, no analysis was appropriate as a gradient sufficient for these analyses was not evident in the available data sets (see Figure 10d). For example, some metrics in the southern region had too few sites with good biological communities and did not show a good relationship between the nutrient or stressor and the biological metrics (Figure 10d). This suggests that many streams in this region are enriched and that additional data is needed from less enriched streams in the region. Although threshold analyses were more difficult in the southern region, there were still a sufficient number of good quality sites (*i.e.*, sites that meet biological goals) to derive some thresholds.

The development of river eutrophication criteria is intended to support attainment of the CWA interim goal. This goal is defined in the CWA as:

> *"wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water" (U.S. Code title 33, section 1251 [a] [2])"*

The interim goal of the CWA does not require that all waters must meet goals equivalent to natural or pristine conditions. Rather a goal of restoring waters to the natural condition is more consistent with the definition of the CWA objective *("restore and maintain the chemical, physical, and biological integrity of the Nation's waters"*; U.S. Code title 33, section 1251 [a]). The statistical methods used in this line of evidence are focused on setting minimum goals that support attainment of the CWA interim goal. This is accomplished by the use of metrics that are sensitive to eutrophication and by identifying thresholds that are consistent with attainment of the CWA interim goal. The quantile regression and changepoint analyses identify thresholds that generally correspond to the upper breakpoint or the midpoint of the steep portion of the curve (Figures 10a b, and c). These relationships and the location of thresholds determined using Minnesota data closely correspond to the location of defensible thresholds derived from stressor-response response relationships in Stevenson *et al.* (2008) (see Figure 2 in Stevenson *et al.* [2008]). These thresholds are consistent with the protection of "fishable/swimmable" goals as defined by the interim goal of the CWA and therefore support Minnesota's aquatic life use goals. As a result, the threshold concentrations from each dataset are not intended to represent protection of the natural condition. Additionally, these do not represent pollute-down-to goals and waters that perform better than these goals should be protected.

Description of piecewise quantile regression analysis. Quantile regression provides a mathematical function relating the dependent and independent variables, and accordingly can be used to estimate values of the dependent variable based on a fixed value of the independent variable and vice versa. MPCA used quantile regression analysis to estimate values of the constituent parameters (*i.e.*, TP, chlorophyll *a*, daily DO flux, and BOD_5) that equated with a decrease in the quality of aquatic community health (as measured by changes in the biological metrics listed in Table 11). MPCA applied a piecewise component to its quantile regression analysis. Piecewise regression analysis partitions the relationship between the dependent and independent variable into multiple segments, each of which are fitted by a separate line. The boundaries between the segments function as breakpoints. Piecewise regression provides a better overall fit to relationships that exhibit multiple functions over the entire response gradient.

Piecewise regression can produce two breakpoints: 1) the point at which initial adverse responses to nutrients occur and 2) the point at which no significant additional response to nutrients occurs. This phenomenon is consistent with the conceptual model of nutrient response, in which an initial amount of nutrient increase results in little or no effect on aquatic community health response until it reaches a point where increasing nutrient concentrations result in a continuous increasing response and decline in aquatic community health, but at some higher concentration of the nutrient there is little or no additional response to aquatic community health, because the aquatic system by then is saturated with nutrients and little further response by the aquatic community occurs. As would be expected, the Minnesota nutrient data exhibit this pattern as observed on pages 143-176 of the Eutrophication TSD.

For many of the statistically significant measures of aquatic community health, the data exhibited this three-segment, two breakpoint function.

> In the Minnesota datasets used for this study, a distinct wedge with breakpoint(s) (Figures 10a, b and c) was most commonly observed. The "upper plateau" (see Figures 10a and c) occurred at generally low levels of nutrients or stressors and was characterized by high variability in the biological metric. The steep portion of the wedge occurred at moderate levels of the nutrient or stressor and indicated that a threshold had been crossed and that biological condition was declining. At higher levels of nutrients or stressors there was often a lower breakpoint that corresponded to low biological metric scores indicating that the response variable had largely reached bottom and was not declining or declining at a much slower rate (see Figures 10a and b). Additive quantile regression smoothing and changepoint analyses were both effective with this type of dataset. (Eutrophication TSD, p. 30)

This scenario provides the upper and lower ends and the range of values that define aquatic life protection. The initial point clearly meets the interim goal of the CWA, but may be more protective than necessary and could incur unnecessary costs on the regulated community. As one proceeds along the response gradient, additional disturbance occurs and at some point that level of disturbance reaches a point that corresponds with impairment of the aquatic life use. The challenge with relationships that have two breakpoints is identifying a point within the two breakpoints that protects aquatic life uses, while not being over-protective and incurring unnecessary substantial costs to stakeholders. As EPA explained in its Guidelines for Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses (EPA, 1985):

> Criteria should attempt to provide a reasonable and adequate amount of protection with only a small possibility of considerable overprotection or under protection. It is not enough that a national criterion be the best estimate that can be obtained using available data; it is equally important that a criterion be derived only if adequate appropriate data are available to provide reasonable confidence that it is a good estimate.

The application of piecewise AQRS required that MPCA select the point along the multiple segments corresponding to unacceptable change in aquatic community health. In most cases, the piecewise AQRS resulted in a three-segment function, that is, having both an upper and lower breakpoint, but in some cases, the piecewise AQRS resulted in a two-segment function, that is, having only an upper breakpoint. Where the analysis indicated only an upper breakpoint or where the analysis indicated two breakpoints and the upper breakpoint was statistically significant, MPCA selected the upper breakpoint as the threshold. Otherwise, MPCA used the midpoint of the two breakpoints as the threshold for aquatic life impairment. MPCA describes its protocol for threshold selection on pages 32-33 of the Eutrophication TSD:

Once the 75th percentile quantile regression was fitted, threshold concentrations were determined using the fits. In datasets where both upper and lower breakpoints were present, concentrations for the midpoint between the breakpoints and upper breakpoint were determined (see Figure 11a). If no upper breakpoint was present then the midpoint between the lower breakpoint and the lowest stressor value was used (see Figure 11b). If an upper breakpoint was present, but no lower breakpoint was present (see Figure 11c) then the threshold concentration was determined using the upper breakpoint. A chi-squared test was performed in Sigma Plot ver. 11 (Systat Software 2008) to determine if there was a significant difference in the biological metric scores above and below the threshold concentration determined by AQRS. In cases where any of the treatments within the contingency table had fewer than five observations, a Fisher Exact Test was performed in SigmaPlot ver. 11 (Systat Software 2008). Threshold concentrations that were not significant were not used in further analyses. In cases where both the upper breakpoint and midpoint threshold concentration could be identified, the upper breakpoint was used if it was significant. If the upper breakpoint was not significant, then the midpoint breakpoint was used if it was significant. The process for testing and selecting threshold concentrations is provided in Figure 12.

A comment was raised during Minnesota's public review period regarding whether the selection of the midpoint under piecewise quantile regression was protective of aquatic life uses and whether the initial breakpoint is more protective of aquatic life. MPCA identified the range over which change occurs and selected a point neither at the end of the range where aquatic life use impairment was nearly certain, nor at the end of the range where impairment likely had not yet occurred. MPCA's selection of the midpoint is based on sound scientific rationale, given that 1) the analyses demonstrate that the effect on measures of aquatic community health occur over a range and not a specific value of the eutrophication indicator concentrations and 2) there is no evidence in the Minnesota data or analyses that the midpoint is not protective of aquatic life uses. Additionally, MPCA considered values predicted from additional statistical analyses, multiple estimates of reference conditions, and available literature values as described in Step 4 below to confirm that the biologically-based thresholds generated from the piecewise regressions are plausible and appropriate. Further, as discussed above, some candidate thresholds were derived using the upper breakpoint, reflecting the point where initial change occurs and there is a greater level of protection.

MPCA used quantile regression rather than basic "linear" regression for the piecewise regressions. Whereas linear regression estimates the *mean* of the response variable (through the method of least squares), quantile regression estimates a specific quantile of the response variable. Calculating the regression line at a higher quantile is useful where there may be other stressors that influence the dependent variables, because it allows the regression to focus on the points that are more likely to be affected primarily by the stressor of interest, thereby providing a better estimation function between the response variable and stressor interest.

Quantile regression is well suited for the wedge-shaped plots (caused by heterogeneous variance; *i.e.,* heteroscedasticity) that are common with biological monitoring data (Terrell *et al.* 1996, Koenker & Hallock 2001, Cade & Noon 2003, Bryce *et al.* 2008; see Figure 8). These wedge-shaped plots are the result of the limitation of biological

> attributes (*e.g.,* taxa richness) by the variable of interest on the outer or upper edge of the wedge (Bryce *et al.* 2008; see Figure 8). Limitations to biological measures inside the wedge are caused by other unmeasured variables (Figure 8). In the case of this work, nutrients can lower biological condition through alteration of DO levels or shifts in food resources or habitat. However, there are also a number of other factors (*e.g.,* sediment, habitat) that can also limit biological condition in Minnesota streams and rivers. As a result of these different factors reducing biological measures, there is unequal variation of the response variable at different levels of the predictor variable. This unequal variation often makes field-derived data (*e.g.,* biomonitoring data) less suitable for the more traditional least squares regression. Quantile regression differs from least squares regression in that it estimates the median (*i.e.,* 50th quantile) or other quantiles whereas least squares regression estimates the mean. Another advantage of quantile regression is that extreme outliers do not impact regression quantile estimates (Terrell *et al.* 1996). (Eutrophication TSD, p. 26)

Further, MPCA applied additive smoothing to the quantile regression. MPCA's rationale for using AQRS and its selection of the 75th quantile is explained on pages 31-32 of the Eutrophication TSD:

> Additive quantile regression smoothing ("rqss" in "quantreg" package; Koenker 2009) was performed in the program R ver. 2.10.0 (R Development Core Team 2009). This method is similar to linear quantile regression, but instead of fitting a single line to the data, this approach fits a regression line to subsets of the data (see Figure 11). As a result, additive quantile regression smoothing (AQRS) can also be used to identify changepoints in addition to fitting the outside of the data wedge. The 75th percentile ($\tau = 0.75$) was used with additive quantile regression smoothing to minimize the effect of outliers. This was important because there is a tendency for increasing variation in the estimates as τ approaches 1 in some datasets (Cade & Noon 2003). In addition some of the smaller datasets could not be effectively fit with τ much greater than 0.75. The additive quantile regression smoothing approach required the selection of a lambda (λ) value which determines the amount of smoothing. Values of λ were selected by eye on how well the line fit the outside of the curve and was not affected by single values. Fits were selected by how well they fit the outside of the wedge while minimizing the number of breakpoints. Identification of 3 or 2 breakpoints was optimal. An F-test was used to determine if the regression fit reduced model deviance. 90% confidence bands were also determined to examine regression fits. Following the selection of a good, parsimonious fit, the relationship was examined to determine if it would be used for threshold concentration determination. Metrics were eliminated if the F-test was not significant at the $\alpha = 0.05$ level. In addition, if the metric responded in a manner contrary to the predicted response or had no response it was not included in further analyses.

MPCA's use of changepoint analysis. Changepoint analysis identifies the point on the response gradient where the most change occurs to the dependent variables (*i.e.,* aquatic community health) per unit increase of the independent variable (*i.e.,* TP, chlorophyll *a*, daily DO flux, or BOD_5). MPCA describes its specific application of changepoint analysis on pages 33-34 of the Eutrophication TSD:

> Changepoint analysis was performed in the program R ver. 2.10.0 (R Development Core Team 2009) using the regression tree analysis ("rpart" in the "rpart" package; Therneau & Atkinson 2008). This method identifies thresholds by dividing samples into two groups based on differences in both their mean and variance (Qian *et al.* 2003). Trees were constrained to a single split with a bucket size of 5 samples or 10% of the sample depending on which was larger (*e.g.,* Figure 13). 90% confidence bands were determined using a bootstrap analysis which resampled 1000 times. Bootstrap analysis was performed in the program R ver. 2.10.0 (R Development Core Team 2009) using the bootstrap function ("boot" in the "boot" package; Canty & Ripley 2009). Since regression tree analysis will identify a changepoint in any dataset, a significance test was applied to determine if the changepoint was significant at the $\alpha = 0.05$ level. A chi-squared test was performed in Sigma Plot ver. 11 (Systat Software 2008) to determine if there was a significant difference in the biological metric scores above and below the threshold concentration determined by regression tree analysis. In cases where any of the treatments within the contingency table had fewer than five observations, a Fisher Exact Test was performed in SigmaPlot ver. 11 (Systat Software 2008). Threshold concentrations identified from non-significant changepoints were not used in further analyses.

EPA Stressor-response Guidance on pages 53-54 support the use of changepoint analysis in nutrient criteria development, especially where supported by other lines of evidence suggesting a threshold change in the dependent variable.

> Non-parametric changepoint analysis (nCPA) is a method for estimating the position of thresholds or changepoints in bivariate relationships, which, in some cases, provide natural candidates for nutrient criterion. When scatter plots suggest that a threshold or sudden change in the statistical attributes of the dependent variable exist in the relationship between a stressor and a response, changepoint analysis can be used to identify the point at which the change occurs (Breiman *et al.* 1984, Pielou 1984, Qian *et al.* 2003). In addition to visual evidence of a changepoint (*e.g.*, as observed in a scatter plot), an ecological understanding of the system may indicate that a changepoint exists, especially in systems that frequently exhibit non-linear responses (*e.g.*, May 1977, Odum *et al.* 1979, Connell and Sousa 1983, Scheffer *et al.* 2001, Brenden *et al.* 2008). In streams, one response to long-term nitrogen/phosphorus pollution that has been observed was a non-linear shift in primary producers from microalgae to one dominant moss species (Slavik *et al.* 2004). nCPA has been used for identifying thresholds in plant and invertebrate responses to nutrient stressors in freshwaters (King and Richardson 2003, Qian *et al.* 2003).

A comment was raised during Minnesota's public review period questioning the validity of changepoint analyses in deriving nutrient criteria and stating that EPA's SAB review of EPA's Stressor-response Guidance cautioned against the misuse of changepoint analysis. MPCA responded that it recognizes that the SAB report recommends that results from changepoint analysis be associated with biological significance and designated uses. In its response, MPCA provided two reasons as to why the results of its changepoint analysis are associated with biological significance: 1) For most eutrophication indicator/biological metric combinations, the changepoints occur in the middle or the early response portions of the response curve, as observed on pages 142-176 of the Eutrophication TSD. It follows logically that changepoints occurring early in the response curve likely are associated with protected aquatic life uses, because aquatic life impairment would not occur prior to the point of early response. 2) The thresholds from the piecewise regressions and the changepoint analyses generally agree, further supporting that the changepoints occur between the points of early and middle levels of response.

EPA agrees with MPCA that the changepoints in Minnesota's data generally occur on the early and middle response portions of the curve. Although there are not biological metric scores to which aquatic life use protection is linked in Minnesota, there is sound scientific rationale to conclude that, where changepoints can be linked to early levels of response, it is reasonable to infer that the changepoints are protective of aquatic life uses, given that impairment of aquatic life uses is unlikely to occur prior to the early portion of the response curve. Further, MPCA's derivation method of using the 25^{th} percentile of all thresholds obtained by changepoint analysis and piecewise regressions effectively considers only those changepoints that occur on the early portions of the response curves. This is because the thresholds from the piecewise regressions and the changepoint analyses generally agree. Therefore, the final threshold selection (*i.e.*, using the 25^{th} percentile of individual thresholds) is based upon changepoints that occur in the early portion of the response curve.

Finally, as noted in the Stressor-response Guidance, quantile regression and changepoint analysis provide valid approaches for characterizing the relationships between nutrient concentrations and biological responses. Further, the SAB comments on the draft Stressor-response Guidance requested further details regarding the use of these approaches, but did not question their validity. In particular, the SAB notes that "The six methods identified in the Guidance generally provide appropriate options for describing stressor-response relationships that may be sufficiently predictive to support setting numeric nutrient criteria." (SAB review of EPA's draft Stressor-response Guidance, p.23). For all of these reasons, MPCA's use of changepoint analysis was based on sound scientific rationale.

A comment was made during Minnesota's public review period regarding whether the criteria, which are based on stressor-response, are scientifically accurate for small streams, because the relationships between TP and the response indicators used in deriving the criteria were based on data from mid to large rivers and small streams perform significantly different than large streams. The commenter requested that MPCA develop separate criteria for streams *vs.* rivers.

As an initial matter, MPCA correctly noted that the commenter's statement is not correct, as no statistically significant differences in the biologically-based thresholds were identified between streams and rivers within any of the three regions (Eutrophication TSD, Figure 48, p. 75). Aside from clarifying the technical aspects of the issue, MPCA observed that although not statistically significant, eutrophication indicator threshold concentrations for rivers do appear to be somewhat lower than stream eutrophication indicator response thresholds and that these differences were driven by the physical characteristic of these systems. Specifically, rivers are more likely than streams to have the physical conditions (*i.e.*, greater residence time, less shading, etc.) to grow undesirable levels of algae. However, despite this general tendency, there are streams in

Minnesota where aquatic life will be impaired by phosphorus concentrations at or above the TP criterion because the physical conditions within these streams are suitable to grow large amounts of algae. Finally, MPCA addressed this concern by structuring the criteria so that both TP and at least one response variable must be exceeded before concluding that aquatic life uses are not being protected. Consequently, MPCA's response to the comment that separate criteria should be developed for streams is based on sound scientific rationale.

In conclusion, for the reasons described above, MPCA's approach for deriving its eutrophication indicator thresholds is based on sound scientific rationale. The indicator parameters comprising the criteria demonstrate significant relationships to designated use protection (aquatic community health protection) and are supported conceptually by MPCA's conceptual model. MPCA used accepted statistical analysis tools for deriving thresholds to determine the concentrations of TP, chlorophyll *a*, DO flux and BOD necessary to ensure that aquatic community health is protected. In particular, MPCA's approach to indicator parameter selection, evaluation of the stressor-response relationships, and identification of response thresholds is based on sound scientific rationale.

IV.A.3.d. Step 4: Evaluate stressor-response relationships and document analysis

As described above, the fourth and final step in the four-step process for development of nutrient criteria protective of aquatic life uses set forth in the Stressor-response Guidance is to systematically evaluate the criteria that were developed after following the first three steps of the process.

> Before finalizing candidate criteria based on stressor-response relationships, one should systematically evaluate the scientific defensibility of the estimated relationships and the criteria derived from those relationships. More specifically, one should consider whether estimated relationships accurately represent known relationships between stressors and responses and whether estimated relationships are precise enough to inform decisions. (EPA Stressor-response Guidance, p. 65)

The Stressor-response Guidance recommends that the steps that should be included in the evaluation process are validation of the estimated stressor-response relationships, consideration of implementation issues, and documentation of the analysis used to derive the criteria. (EPA Stressor-response Guidance, pp. 65-71) MPCA's approach does include validation of the estimated stressor-response relationships, consideration of implementation issues, and documentation of the analysis used to derive the criteria. A detailed description of MPCA's validation method is provided below, in this section. In summary:

- MPCA evaluated the results of its stressor-response based thresholds against independent estimates of the same indicators, based on different locations, data sets, and analytical tools.
- MPCA addressed criteria implementation through its use of ecoregional criteria and a dual-parameter criteria approach, in which both a response variable and a causal variable must be exceeded for a stream to be deemed impaired.

- MPCA documented its criteria derivation methodology, including criteria validation steps, extensively and transparently in its Eutrophication TSD and its public rulemaking documents, most notably, its SONAR.

Regarding the validation step, the Stressor-response Guidance recommendations include use of *a posteriori* (*i.e.*, after having derived thresholds on stressor-response relationships) methods:

> *A posteriori* approaches for evaluating whether an estimated stressor-response relationship is sufficiently accurate compare the relationship with other independent estimates of the same relationship. One such approach would be to compare an estimated relationship with similar relationships documented in other studies. Observing a similar relationship in a different location and data set would lend support to the idea that the estimated relationship in the current study was accurate (see, for example, Jeppesen *et al.* 2005). (EPA Stressor-response Guidance, p. 66)

Previous EPA guidance also recommends that the results of stressor-response based thresholds be compared to thresholds from other lines of evidence (EPA Nutrient Criteria Development Guidance for Streams, 2000, pp. 13-14):

> Three general approaches for criteria setting are discussed in this manual: (1) identification of reference reaches for each stream class based on best professional judgment (BPJ) or percentile selections of data plotted as frequency distributions, (2) use of predictive relationships (*e.g.*, trophic state classifications, models, biocriteria), and (3) application and/or modification of established nutrient/algal thresholds (*e.g.*, nutrient concentration thresholds or algal limits from published literature).
>
> Initial criteria should be verified and calibrated by comparing criteria in the system of study to nutrients, chl *a*, and turbidity values in waterbodies of known condition to ensure that the system of interest operates as expected. A weight of evidence approach that combines any or all of the three approaches above will produce criteria of greater scientific validity. Selected criteria and the data analyzed to identify these criteria will be comprehensively reviewed by a panel of specialists in each USEPA Region. Calibration and review of criteria may lead to refinements of either derivation techniques or the criteria themselves. In some instances empirical and simulation modeling, or data sets from adjacent States/Tribes with similar systems may assist in criteria derivation and calibration.

EPA's Nutrient Criteria Development Guidance, 2000, does not require that all three approaches be utilized in deriving criteria but notes that, "a weight of evidence approach that combines one or more of the three approaches…will produce criteria of greater scientific validity." (p. 94) MPCA used all three approaches, in that predictive relationships were used to derive biologically-based response thresholds (under Step 3, above), which were subsequently compared to Minnesota-based reference condition data and concentration thresholds from the published literature (under Step 4, this section). MPCA's approach for evaluating the estimated stressor-response relationships is consistent with both EPA's Stressor-response Guidance and EPA's Nutrient Criteria Development Guidance, in that it relies heavily on assessing the accuracy of the stressor-response based thresholds, against the results of several other lines of evidence. MPCA considered that using a multiple line of evidence approach is an effective and broadly-used approach for evaluating the accuracy of its stressor-response relationships:

> The multiple lines of evidence approach we have used to develop eutrophication criteria is well supported in the literature. Stevenson *et al.* (2008), for example, describe how algae and phosphorus relationships, threshold analysis and frequency distributions can guide development of nutrient criteria. In their example they focus on benthic algal growth; however, they acknowledge that this approach could be applied to other stream biota as well. In summary they note – "multiple analytical approaches can and should be used when developing nutrient criteria to provide the diversity of information that justify criteria to stakeholders and increase the probability of successful management actions. (Eutrophication TSD, p. 91)

The first of the lines of evidence that MPCA considered in evaluating the eutrophication indicator thresholds was the results from simple linear and serial regression analyses. That is, MPCA used regression, in some cases serially, to derive additional candidate values for chlorophyll *a*, daily DO flux, and BOD_5 from the TP and BOD_5 thresholds described in Step 3 above. MPCA conducted quantile regression using the 75^{th} quantile, and the regression equations came from the original analyses of TP, chlorophyll *a*, daily DO flux, and BOD_5. (Eutrophication TSD, pp. 75-78)

The second line of evidence was reference condition concentrations, from three data sets: 1) minimally impacted Minnesota streams, 2) EPA ecoregion criteria summaries, and 3) Minnesota reference sites from STORET. The reference condition approach to deriving concentrations of the eutrophication indicator variables is based upon the hypothesis that reference sites reflect minimal increases in nutrients and thus aquatic life uses are likely to be attained.

> One approach that may be used in developing criteria is the reference reach approach. Reference reaches are relatively undisturbed stream segments that can serve as examples of the natural biological integrity of a region. (EPA Nutrient Criteria Development Guidance for Streams, p. 94)

In identifying reference water conditions, a point along the distribution of reference waters is selected that would not be so high as to result in falsely identifying waters as being impaired but still is representative of minimally disturbed conditions. EPA's Nutrient Criteria Development Guidance for Streams, page 94, recommends several ways of developing reference-based criteria:

> There are three ways of using reference reaches to establish criteria.
>
> 1. Characterize reference reaches for each stream class within a region using best professional judgement and use these reference conditions to develop criteria.
> 2. Identify the 75th percentile of the frequency distribution of reference streams for a class of streams and use this percentile to develop the criteria.

3. Calculate the 5th to 25th percentile of the frequency distribution of the general population of a class of streams and use the selected percentile to develop the criteria.

MPCA considered both the 75th percentile of reference conditions and the 25th percentile of all waters in developing estimates of reference condition. The final line of evidence used by MPCA is the threshold values identified in the literature as protective of aquatic life uses in the upper Midwest.

The results from the multiple lines of evidence are provided in tabular form in Tables 21-23 of the Eutrophication TSD, pages 92-94 (reproduced as Table IV.4, below):

Table IV.4. Summary of evidence used to develop Minnesota's river eutrophication criteria (Eutrophication TSD, Tables 21-23, pp. 92-94).

Table 21: Summary of evidence used to develop recommended river eutrophication criteria for the Northern River Nutrient Region (* indicates threshold is based on statewide data; Abbreviations: IQR = Interquartile Range; %ile = Percentile; TP = Total Phosphorus; Chl-a = Chlorophyll-a; BOD_5 = Biochemical Oxygen Demand; DO Flux = Diel Dissolved Oxygen Flux). ["25th %ile Threshold Concentrations" are the biological change-associated thresholds using the AQRS and change point analyses; "Prediction Concentrations" are linear and serial regression derived values based on the final thresholds from the AQRS and change point analyses.]

Line of Evidence	TP (µg/L)	Chl-a (µg/L)	DO Flux (mg/L)	BOD_5 (mg/L)
25th %ile Threshold Concentrations (Table 18)	44	21*	3.1*	-
IQR for Minimally impacted MN streams (Table 20c)	40-70	-	-	1.0-1.7
IQR for USEPA Ecoregion Summaries (Table 20c)	32-70	-	-	-
75th %ile for MN Reference Sites (Table 20d)	61	3	-	2.0
Predicted Concentration Using TP-Chla-BOD5 Threshold Models (Fig. 49)	41-72	5-10	-	-
Predicted Concentration Using TP-BOD5 Threshold Models (Fig. 50)	70-78	-	-	-
Predicted Concentration Using 75th %ile water quality models (Table 15)	-	5-6	3.0	1.3-1.4
Recommended Criterion (Table 24)	50	7	3.0	1.5

Table 22: Summary of evidence used to develop recommended river eutrophication criteria for the Central River Nutrient Region (* indicates threshold is based on statewide data; Abbreviations: IQR = Interquartile Range; %ile = Percentile; TP = Total Phosphorus; Chl-a = Chlorophyll-a; BOD_5 = Biochemical Oxygen Demand; DO Flux = Diel Dissolved Oxygen Flux). ["25th %ile Threshold Concentrations" are the biological change-associated thresholds using the AQRS and change point analyses; "Prediction Concentrations" are linear and serial regression derived values based on the final thresholds from the AQRS and change point analyses.]

Line of Evidence	TP (µg/L)	Chl-a (µg/L)	DO Flux (mg/L)	BOD_5 (mg/L)
25th %ile Threshold Concentrations (Table 18)	110	21*	3.1*	2.1
IQR for Minimally impacted MN streams (Table 20c)	70-170	-	-	1.6-3.3
IQR for USEPA Ecoregion Summaries (Table 20c)	40-200	-	-	-
75th %ile for MN Reference Sites (Table 20d)	139	5	-	2.0
Predicted Concentration Using TP-Chla-BOD5 Threshold Models (Fig 49)	83-107	13-21	-	-
Predicted Concentration Using TP-BOD5 Threshold Models (Fig. 50)	118-121	-	-	-
Predicted Concentration Using 75th %ile water quality models (Table 15)	-	18	3.9	1.8-1.9
Recommended Criterion (Table 24)	100	18	3.5	2.0

Table 23: Summary of evidence used to develop recommended river eutrophication criteria for the Southern River Nutrient Region (* indicates threshold is based on statewide data; Abbreviations: IQR = Interquartile Range; %ile = Percentile; TP = Total Phosphorus; Chl-a = Chlorophyll-a; BOD_5 = Biochemical Oxygen Demand; DO Flux = Diel Dissolved Oxygen Flux). ["25th %ile Threshold Concentrations" are the biological change-associated thresholds using the AQRS and change point analyses; "Prediction Concentrations" are linear and serial regression derived values based on the final thresholds from the AQRS and change point analyses.]

Line of Evidence	TP (µg/L)	Chl-a (µg/L)	DO Flux (mg/L)	BOD_5 (mg/L)
25th %ile Threshold Concentrations (Table 18)	145	21*	3.1*	3.1
IQR for Minimally impacted MN streams (Table 20c)	185-320	-	-	2.4-6.1
IQR for USEPA Ecoregion Summaries (Table 20c)	170-403	-	-	-
75th %ile for MN Reference Sites (Table 20d)	302	19	-	-
Predicted Concentration Using TP-Chla-BOD5 Threshold Models (Fig. 49)	129-149	28-39	-	-
Predicted Concentration Using TP-BOD5 Threshold Models (Fig. 50)	168-193	-	-	-
Predicted Concentration Using 75th %ile water quality models (Table 15)	-	18	4.8	2.5-2.7
Recommended Criterion (Table 24)	150	35	4.5	3.0

MPCA evaluated the various lines of evidence in determining the final criteria values. MPCA's selection process for the final criteria is explained on page 91 of the Eutrophication TSD:

> The multiple lines of evidence, as described above, provide the basis for selection of ecoregion-based criteria. This approach does not rely heavily on the reference condition, a recommended approach in early EPA guidance (*e.g.* USEPA 2000a-c), as a primary basis for criteria selection. Rather, the datasets and summaries provided in that guidance help place proposed criteria in perspective with the overall distributions for each ecoregion. Our approach emphasized the threshold concentrations developed from the biomonitoring data using quantile regression and changepoint analysis (Table 18). Further, we chose to begin with selection of TP criteria, since TP had the largest number of threshold concentrations developed for each RNR (Table 18). Once selected, we sought protective response variables based on Table 18, the serial regressions (Table 15), and tried to ensure there was good correspondence between TP and the primary response variable Chl-a (Figure 32).

MPCA's use of multiple lines of evidence to evaluate its piecewise regression and changepoint analysis-based thresholds (denoted in Tables above as the "25th %ile Threshold Concentrations") and its final criteria selection process is based on sound scientific rationale. EPA guidance recommends that the different lines of evidence be compared and weighed qualitatively in selecting a final value. (EPA Stressor-response Guidance, p. 71)

> If several different response variables have been analyzed, then the different candidate criteria derived for each variable should be compared and discussed. The relative precision and accuracy of stressor-response relationships used to derive different candidate criteria can be compared, and used qualitatively to weight different candidate criteria when selecting a final value. Also, candidate criteria derived using other methods (*e.g.*, reference site distributions, literature values) can be compared qualitatively with criteria derived using stressor-response relationships.

Each of the supporting lines of evidence used by MPCA in itself is supported by sound scientific rationale, consistent with EPA's Stressor-response Guidance and EPA's Nutrient Criteria Development Guidance for Rivers and Streams:

> A stressor-response relationship estimated by SLR predicts the value of the response variable, given a particular nutrient concentration. Hence, if the value of the response variable that supports the designated uses is known for a waterbody, the stressor-response relationship can "translate" this response threshold to a numeric criterion value. In many cases, a threshold for the selected response variable is available that defines values of the response variable where designated uses are supported. (EPA Stressor-response Guidance, p. 37)

> Identification of reference streams allows the investigator to arrange the streams within a class in order of nutrient condition (*i.e.*, trophic state) from reference, to at risk, to impaired. Defining the nutrient condition of streams within a stream class allows the manager to identify protective criteria and determine priorities for management action. Criteria developed using reference reach approaches may require comparisons to similar systems in States or Tribes that share the ecoregion so that criteria can be validated, particularly when minimally-disturbed systems are rare. (EPA Nutrient Criteria Development Guidance for Streams, p. 95)

> In addition to using the 'reference reach' concept or applying predictive relationships to establish criteria for trophic state variables, other methods to consider include using thresholds and criteria already recommended in the literature. These approaches might be used as limits if identifying reference reaches proves difficult or as temporary measures until reference reaches can be adequately described. (EPA Nutrient Criteria Development Guidance for Streams, p. 100)

MPCA's protocol for the selection of the final eutrophication criteria emphasizes regionally and locally-based data as well as stressor-response information. Such a protocol is based on sound scientific rationale and consistent with EPA guidance. In fact, the data used by MPCA for the regression-based analyses and the reference condition concentrations comes entirely from Minnesota rivers. EPA's Ecoregional Criteria for Rivers and Streams, VI, (2000) recommend such a preference in nutrient criteria development:

> Wherever possible, develop nutrient criteria that fully reflect localized conditions and protect specific designated uses using the process described in EPA's Technical Guidance Manuals for nutrient criteria development. Such criteria may be expressed either as numeric criteria or as procedures to translate a State or Tribal narrative criterion into a quantified endpoint in State or Tribal water quality standards. (p. iii)

> In 1995, EPA gathered a set of national experts and asked the experts how to best deal with the national nutrient problem. The experts recommended that the Agency not develop single criteria values for phosphorus or nitrogen applicable to all water bodies and regions of the country. Rather, the experts recommended that EPA put a premium on regionalization, develop guidance (assessment tools and control measures) for specific

waterbodies and ecological regions across the country, and use reference conditions (conditions that reflect pristine or minimally impacted waters) as a basis for developing nutrient criteria. (p. 1)

In conclusion, MPCA's approach includes evaluating the results of the estimated stressor-response relationships against independent threshold estimates of the same indicators, using qualitative analysis to weight different candidate criteria when selecting final criteria values, the use of ecoregional criteria and a dual-parameter approach, and extensive and transparent documentation of its methodology and results in its technical support documents and its public rulemaking documents. Therefore, MPCA's approach for deriving the multi-indicator eutrophication criteria are based on sound scientific rationale and are consistent with EPA guidance.

IV.A.3.e. Conclusion regarding Minnesota's multi-indicator eutrophication criteria for protection of aquatic life for rivers and streams

For the reasons described above, EPA determines in accordance with 40 CFR 131.5(a)(2) and 131.11(a) that Minnesota's multi-indicator eutrophication criteria for rivers and streams are based on sound scientific rationale and protective of Minnesota's aquatic life use designations.

IV.B. Multi-indicator eutrophication criteria for protection of aquatic life for segments of the Crow River and Crow Wing River

IV.B.1. Multi-indicator criteria for segments of the Crow River and Crow Wing River

MPCA adopted the following unique multi-indicator eutrophication criteria for segments of the Crow River and the Crow Wing River (Table 11 of the SONAR, Book 2, page 65), reproduced as Table IV.5, below):

Table IV.5. Draft river eutrophication standards ranges by River Nutrient Region for Minnesota and site-specific values for specific river AUIDs.

	Nutrient		**Stressor**	
	TP (µg/l)	**Chl-a (µg/l)**	**DO Flux (mg/L)**	**BOD_5 (mg/L)**
Crow Wing River	75	13	3.5	1.7
Crow River	125	27	4.0	2.5

IV.B.2. How Minnesota derived its multi-indicator criteria for segments of the Crow River and Crow Wing River

As described in Section IV.A of this document, MPCA developed three sets of ecoregion-based eutrophication criteria for rivers and streams to reflect regional differences in the state in terms of land use, soils, geomorphic patterns, forestation and other characteristics that impact shading, turbidity, stream flow and depth. Two water body segments of the state – a segment of the Crow River and a segment of the Crow Wing River – are in transitional areas bordering two different regions (the Crow Wing River is near the boundary of the North and Central regions; the Crow

River is near the boundary of the Central and South regions). In addition to being in transitional areas, these segments are somewhat unique in that they are formed by the confluence of two relatively equal size rivers that are located in different ecoregions. Specifically, the segment of the Crow Wing River at issue is formed by the confluence of one river that is in the North region and a second river from the Central region; while the segment of the Crow River at issue is formed by the confluence of one river that is in the Central region and a second river that is in the South region. Given these two segments' locations in transitional areas between two regions, MPCA determined that the multi-indicator criteria for these two segments should reflect the mid-point between the criteria for the two bordering ecoregions.

Additionally, the Central RNR is a transitional area between the North RNR and the South RNR and identifies physical factors that contribute to its transitional nature: (SONAR, Book 2, p. 61)

> The Central RNR, which consists of the NCHF and DA ecoregions, is a transitional area between the forest and wetland dominated North and agriculturally dominated South RNR (Exhibit EU-1). While land uses have changed toward increased developed land in recent years, the CHF and DA land use percentages are quite different from those of the NLF and NMW ecoregions, which are dominated by forested and wetland (water) landuse. Because of differing soils, landform, and landuse, streams draining the Central RNR landscapes are more nutrient-rich than North RNR streams (Table 9).

IV.B.3. Minnesota's multi-indicator eutrophication criteria for segments of the Crow Wing and Crow Rivers are based on sound scientific rationale and protective of designated aquatic life uses

Minnesota's multi-indicator eutrophication criteria for protection of aquatic life uses for segments of the Crow Wing and Crow Rivers is based on sound scientific rationale and protective of designated uses. MPCA's determination is consistent with the conceptual model described in Section IV.A of this document, which indicates that ecosystem response to eutrophication varies due to the influence of certain factors (*e.g.*, shading, turbidity, depth, and mixing). It follows that the contributions of these factors on eutrophication indicator concentrations necessary to protect aquatic life uses in transitional areas between two regions would fall between the discrete concentrations determined necessary to protect aquatic life uses in each of the two bordering regions, especially where the segments at issue are formed by the confluence of two relatively equal size rivers that are located in different ecoregions. Moreover, it is logical to conclude that 1) some characteristics that drive the need for more stringent criteria in the northern of the two bordering ecoregions at issue are ameliorated in these segments by their blending with the characteristics from the southern region in these transitional areas; 2) some characteristics that allow for less stringent criteria in the southern of the two bordering ecoregions are not as prevalent in these transitional areas because of the blending with the northern bordering ecoregion; and so 3) criteria more stringent than the southern boundary ecoregion are necessary to protect aquatic life uses in the transitional areas, but such criteria can be less stringent than those for the northern boundary ecoregion.

EPA recognizes that the daily DO flux value of 3.5 mg/L for the Crow Wing River segment is at the upper end of the range of daily DO flux thresholds from the two bordering regions, as opposed to the midpoint, which is 3.3 mg/L. In this particular case, there is a sound rationale for using a value other than the midpoint, based on the size of the Crow Wing River after the confluence of the two rivers. Specifically, the Crow Wing River downstream of the confluence of the two upstream rivers becomes deeper, wider, and bigger and thus more productive, and thus greater daily DO flux would be expected. Since the natural conditions in the Crow Wing River (*i.e.*, its hydrology) support increased chlorophyll *a* and DO flux concentrations, there is a sound rationale for expecting that a DO flux of 3.5 mg/L is protective of aquatic life uses.

IV.C. Benthic chlorophyll *a* criterion for protection of recreation and aquatic life

IV.C.1. Benthic chlorophyll *a* criterion

In addition to the multi-indicator eutrophication criteria for rivers and streams, MPCA also adopted the following state-wide, stand-alone criterion for benthic algae (also known as periphyton) for rivers and streams, which are algae that are attached to rocks and other substrates, to protect recreational and aquatic life uses:

> For chlorophyll-*a* (periphyton), the standard is exceeded if concentrations exceed 150 mg/m^2 more than one year in ten.

IV.C.2. How Minnesota derived its benthic chlorophyll *a* criterion for rivers and streams

MPCA determined that designated uses in rivers and streams need to be protected from the adverse effects of excess benthic algal biomass, resulting in the need for a benthic chlorophyll *a* criterion:

> We are proposing a series of nutrient and chlorophyll water quality criteria for the phytoplankton in the water column. It is also appropriate to protect beneficial designated uses of rivers from excess periphyton by setting biomass concentrations, usually in terms of mg chlorophyll per square meter [mg CHL *a*/m^2]. This is consistent with observations of Snelder *et al.* (2004), in their work on New Zealand streams, who note "By focusing on biomass, the analysis is meaningful to stakeholders, which is a key to seeking consensus in environmental planning." (Eutrophication TSD, p. 89)

Based on a review of the scientific literature, MPCA identified multiple studies that identified benthic algal biomass levels that are considered excessive and polluting, from both a recreational and an aquatic life perspective. The studies that MPCA identified that provided algal biomass values for the protection of aquatic recreation uses and aquatic life uses are found on page 29 of the SONAR, Book 2:

> In Montana streams, Suplee *et al* (2008) determined through public surveys that as benthic algal biomass increased, desirability for recreation decreased. Mean biomass levels of $\geq$ 200 mg Chl/m^2 were determined to be excessive, while mean levels $\leq$ 150 – 200 mg Chl/m^2 were determined to be desirable. Welch *et al* (1988) found a biomass range of 100 – 150 mg Chl/m^2 represents a critical level for aesthetic nuisance. Biggs (2000) [Biggs, Barry J.F. Eutrophication of streams and rivers: dissolved nutrient-

chlorophyll relationships for benthic algae, Journal of the North American Benthological Society, March 2000] stated that biomass levels > 150 – 200 mg Chl/m^2 are very conspicuous in streams, are unnaturally high, and would compromise the fishery and recreational value of rivers.

Work by Miltner (2010a) suggests maintaining periphyton below 150 mg Chl/m^2 would be protective for aquatic life uses as well. In this work, he recommends that biomass remain below 107 mg Chl/m^2 for protecting high-quality waters and less than 182 mg Chl/m^2 to ensure minimum DO remains >4.0 mg/L.

Suplee *et al* (2008b) also provide examples of photographs from Montana for excellent quality, diatom-dominated streams, and poor-quality filamentous green algal [*Cladophora*] – dominated streams (Figure 23). Their study showed a clear demarcation in algal type as biomass increased from 150 mg Chl/m^2 to 200 mg Chl/m^2.

Based on this review of the scientific literature, MPCA concluded:

> Rivers shall have an algal biomass not to exceed 150 mg Chl-a/m^2 and not to exceed one-third (1/3) of the stream width, to avoid nuisance algal biomasses that interfere with aquatic recreation designated uses. Dodds *et al* (1997), Dodds & Welch (2000), Welch *et al* (1988), and Suplee *et al* (2008) provide excellent literature reviews and biomass recommendations. More recently, work by Miltner (2010) suggests maintaining periphyton below 150 mg Chl-a /m^2 would be protective for aquatic life uses as well. In this work, he recommends that biomass remain below 107 mg/m^2 for protecting high-quality waters and less than 182 mg/m^2 to ensure minimum DO remains >4.0 mg/L. This further reinforces that a value of 150 mg Chl-a/m^2 is reasonable for protection of aquatic life and recreational uses. Suplee *et al* (2008) also provides example photographs for excellent quality, diatom-dominated streams, and poor-quality filamentous green algal [*Cladophora*] - dominated streams. Their study showed a clear demarcation in algal type as biomass increased from 150 mg Chl-a/m^2 to 200 mg Chl-a/m^2, mediated by nitrogen concentrations (Figure 23). Those studies we have noted here, as well as numerous studies cited in Exhibit EU-1, serve to support the 150 mg Chl-a/m^2 as proposed. (SONAR, Book 2, p. 95)

IV.C.3. Minnesota's benthic chlorophyll *a* criterion for rivers and streams is based on sound scientific rationale and protective of designated aquatic recreation and aquatic life uses

As described above, Minnesota's benthic chlorophyll *a* criterion of 150 mg/m^2 for rivers and streams is based on sound scientific rationale and will protect Minnesota's recreational and aquatic life designated uses.

IV.D. Eutrophication criteria for protection of recreation and aquatic life for the Mississippi River pools and Lake Pepin

IV.D.1. Eutrophication criteria for the Mississippi River pools and Lake Pepin

MPCA has adopted eutrophication criteria for two general types of water bodies: eutrophication criteria for lakes (which MPCA adopted and EPA approved in 2008) and eutrophication criteria for rivers and streams (which MPCA adopted on June 25, 2014, and are addressed above in Section III of this document). As part of this rulemaking, MPCA also adopted site-specific eutrophication criteria for a third type of water body that does not fit neatly into either of these general categories: the Mississippi River pools and Lake Pepin. These site specific criteria are provided in Table IV.6 below:

Table IV.6. Eutrophication criteria for the Mississippi River pools and Lake Pepin

	TP (ug/L)	Chlorophyll a (ug/L)
Pool 1	100	35
Pool 2	125	35
Pool 3	100	35
Lake Pepin (Pool 4)	100	28
Pools 5-8	100	35

IV.D.2. How Minnesota derived its eutrophication criteria for the Mississippi River pools and Lake Pepin

As with the ecoregional eutrophication criteria, MPCA used a stressor-response approach in deriving TP and chlorophyll *a* criteria for the Mississippi River pools and Lake Pepin. In the case of the Mississippi River pools and Lake Pepin, MPCA used a mechanistic model as opposed to a statistical model (*i.e.*, the type of model used for the ecoregional criteria). While a goal of both types of models is to predict relationships between stressor and response variables, mechanistic models do so by evaluating a set of equations that describe the underlying processes in a system, whereas statistical models consider only the data. Mechanistic models are particularly useful in evaluating complex systems, such as the Mississippi River pools and Lake Pepin. The mechanistic model used by MPCA is the LTI UMR-LP model, developed by Limno-Tech, Inc. The model is based on 22 years of in-lake and watershed data for the period from 1985-2006 (Lake Pepin TSD, p. 23). The model was developed for the Lake Pepin TMDL to predict future conditions in Lake Pepin under various nutrient reduction scenarios.

In deriving the criteria, MPCA determined that the most sensitive use in the Mississippi River pools and Lake Pepin is recreational use and that an appropriate endpoint for recreational use protection for these waters is minimization of severe nuisance algal blooms. Hence, MPCA used prevention of severe nuisance algal blooms as the basis for the criteria. Through user perception surveys, MPCA determined that maximum chlorophyll *a* concentrations of 50 μg/L and higher are associated with user perception of severe nuisance algal blooms. Using the LMI URM-LP mechanistic model (described below), MPCA evaluated relationships in Lake Pepin among maximum chlorophyll *a*, summer mean chlorophyll *a*, and TP. MPCA determined that summer mean chlorophyll *a* and TP are associated with maximum chlorophyll *a* and that summer mean chlorophyll *a* and TP thresholds (30 and 100 μg/L, respectively) correspond to avoiding a maximum chlorophyll *a* concentration of 50 μg/L. MPCA applied the TP/chlorophyll *a* relationships from Lake Pepin to the other Mississippi River pools and subsequently derived criteria for chlorophyll *a* and TP criteria that are protective of recreational uses, taking into account variation in residence time between Lake Pepin and the other pools and upstream loading of chlorophyll *a*.

In developing the TMDL, MPCA ran multiple load reduction scenarios on the LTI UMR-LP. In addition to providing load reduction information, the model outputs describe the relationship between TP and chlorophyll *a* and thus MPCA determined that they could also be used for deriving the Lake Pepin and pool site-specific eutrophication criteria. In interpreting these model outputs for criteria setting, it is important to keep in mind that the model outputs reflect the complex nature of the entire Mississippi River pools and upstream system, including substantial upstream and tributary loadings of chlorophyll *a*. MPCA determined that the LTI UMR-LP model is a useful foundational point in deriving criteria because it describes the general TP/chlorophyll *a* relationship for Lake Pepin. However it also likely overstates the in-lake response of chlorophyll *a* to TP because the model includes upstream loadings of chlorophyll *a* and not just in-lake or in pool response.

MPCA applied the relationships observed in Lake Pepin from the LTI UMR-LP model to the other Mississippi River pools because all of these waters share the key characteristic of being somewhere in between rivers and lakes in their response to nutrients. MPCA documented that the amount of algae produced per unit TP is determined at least in part by the residence time of the water in the pool. Consequently, it follows that chlorophyll *a* response per unit TP likely will be less in the pools as compared to Lake Pepin, because Lake Pepin has a substantially longer residence time (Figure IV.3, below).

> A summer-mean flow of 20,000 cfs provides a residence time of about 11 days that is within the 8-14 days, which is often cited as the minimum needed to allow for full algal response to nutrients in lakes. At shorter water residence times, phytoplankton is removed from the system before a standing crop reaches the level determined by the concentration of the limiting nutrient (Pridmore and McBride 1984). (Lake Pepin Eutrophication TSD, p. 8)
>
> Mississippi River navigation Pools 1-8 represent a "transitional" waterbody type between free flowing rivers and true reservoirs. Similar to rivers, water residence time is quite short in all pools, with the exception of Pool 4 (Lake Pepin). (Mississippi River pools TSD, p. 1)

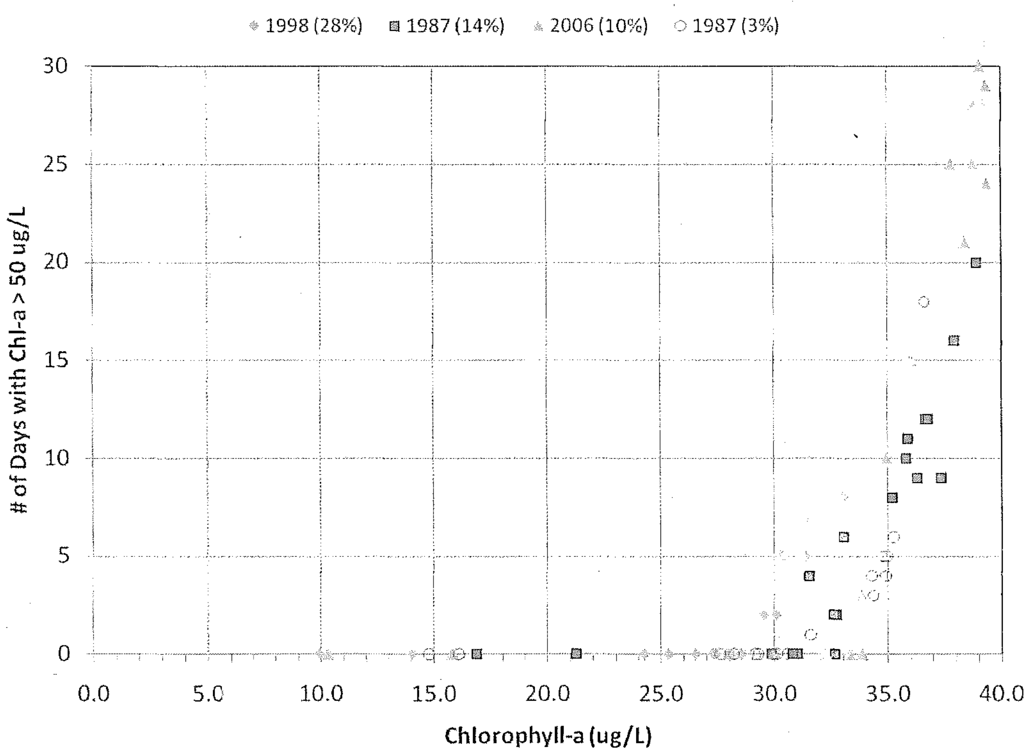
In evaluating TP and summer mean chlorophyll *a* against the number of days in which maximum chlorophyll *a* exceeds 50 μg/L, all modeling runs indicate that summer mean chlorophyll *a* concentrations less than 30 μg/L will result in zero days when chlorophyll *a* is greater than 50 μg/L (Figure 19, page 29, Lake Pepin Eutrophication TSD, Figure IV.4, below). MPCA subsequently set the chlorophyll *a* summer mean criterion for Lake Pepin at 28 μg/L rather than

30 µg/L because of the heavy recreational use of Lake Pepin, to ensure that the recreational use is protected.

Figure IV.3. Depth and residence time of the Mississippi River pools, reproduced from the Mississippi River pools TSD, Figure 1, page 6:

Lock Name or Number	River Mile	Drainage Area (sq mi)	City	Began Operation	Mean depth (m)	Res. Time (days)
1	847.7	19,684	St. Paul, MN	Rebuilt 1938	6.0	<1-2
2	815.2	36,990	Hastings, MN	1931	2.5	2-8
3	796.9	45,170	Red Wing, MN	1938	2.7	1-4
4	752.8	57,100	Alma, WI	1935	5.2	7-28
5	738.1	58,845	Minneiska, MN	1935	---	0.8-1.7
5A	728.3	59,105	Winona, MN	1936	---	0.4 – 0.9
6	714.2	60,030	Trempealeau, WI	1936	---	0.5 – 1.1
7	702.5	62,340	Dresbach, MN	1937	---	0.9-1.9
8	679.1	64,770	Genoa, WI	1937	1.8	1-2

Figure IV.4. Changes in days with chlorophyll *a* > 50 µg/L as a function of summer mean chlorophyll *a*. From the Lake Pepin TSD, Figure 19, page 29.

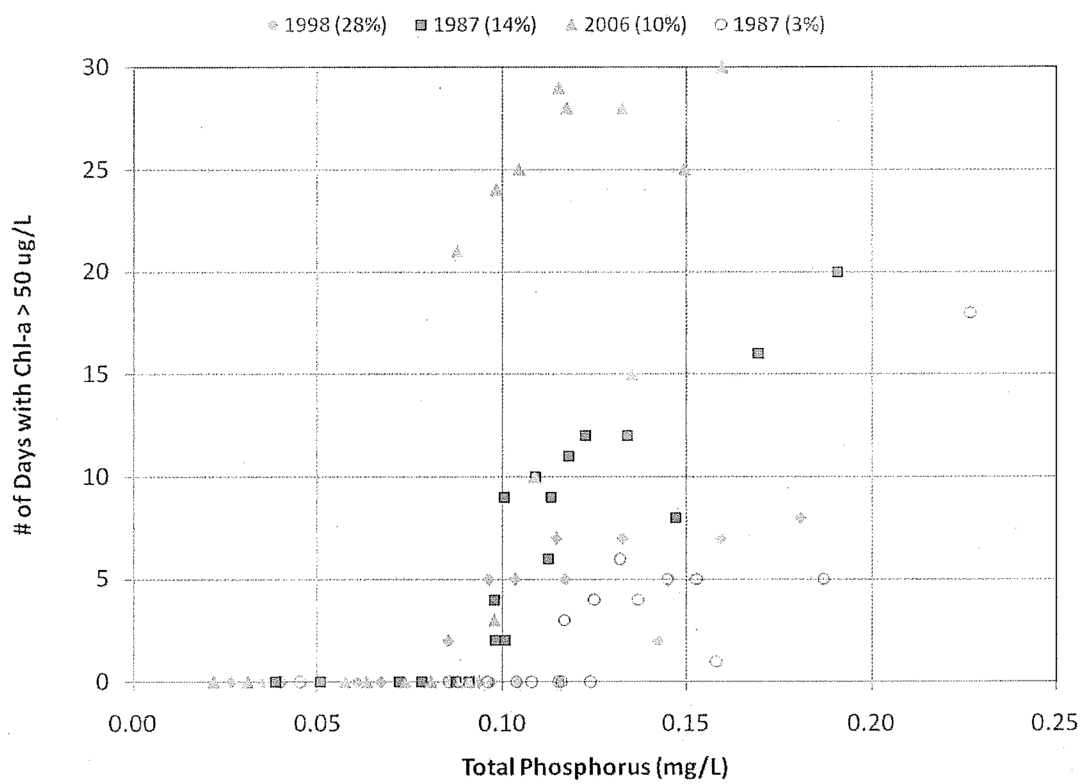


MPCA observed that the residence time in the remaining pools is substantially shorter than in Lake Pepin. A shorter residence period means there will be less time for TP to be converted to chlorophyll *a* and accordingly maximum chlorophyll *a* will be lower for a given average chlorophyll *a* concentration than would be for a water with a longer residence time. Therefore, pools with shorter residence time can tolerate average concentrations of 35 µg/L without exceedance of maximum chlorophyll *a* of 50 µg/L. Accordingly, MPCA set the chlorophyll *a* criterion for the pools at 35 µg/L.

Almost all modeling runs for TP indicate that TP concentrations less than approximately100 ug/L will result in zero days when chlorophyll *a* is greater than 50 µg/L (Figure IV.5, below). Because the LTI UMR-LP model likely overstates the levels of chlorophyll *a* that will result solely from TP in Lake Pepin because the model includes upstream loadings of chlorophyll *a* (not just in-lake production of chlorophyll *a*), the models suggest that there likely will be zero days when TP concentrations below 100 µg/L will result in exceedance of a maximum chlorophyll *a* of 50 µg/L. Accordingly, MPCA set the TP criterion for Lake Pepin at 100 µg/L.

A similar rationale formed the basis for TP criteria for the remaining pools. The LTI UMR-LP model results indicate TP concentrations at or below approximately 100 µg/L avoid exceedance of maximum chlorophyll *a* of 50 µg/L, with few exceptions. Because none of the model runs used zeroed-out upstream loads of chlorophyll *a* or TP, the LTI UMR-LP model outputs likely overstate in-lake chlorophyll *a* production. Consequently exceedance of maximum chlorophyll *a* due to in-lake production likely is less than stated by the model. Additionally, the shorter residence time of the pools, as compared to Lake Pepin, means there will be less time for TP to be converted to chlorophyll *a* and thus a lower summer mean chlorophyll *a* concentration will be produced per unit of TP. For these two reasons, the pools criteria concentrations of 100-125 µg/L TP will avoid exceedance of maximum chlorophyll *a* of 50 µg/L. Accordingly, MPCA set the TP criterion at 100 µg/L for Pools 1, 3, and 5-8 and at 125 µg/L for Pool 2.

Figure IV.5. Changes in days with chlorophyll *a* > 50 µg/L as a function of TP. From the Lake Pepin TSD, Figure 18, page 29.



MPCA also evaluated current fishery conditions to determine whether aquatic life uses likely will be protected by the criteria. Specifically, MPCA determined that, even though current TP and chlorophyll *a* levels in the Mississippi River pools and Lake Pepin exceed the recreation-based criteria, those waters currently have healthy aquatic life and so are not currently impaired for aquatic life and so designated aquatic life uses are expected to be protected by the criteria:

> While emphasis has been placed on meeting aquatic recreational uses these criteria should be protective of aquatic life uses as well. Recent MDNR fishery assessments for Pepin and Pool 4 indicate a healthy and robust fishery (Dietermann 2009). Meerbeek (2009) notes … "They have found submerged aquatic vegetation to be scarce in and above Lake Pepin and along the main and secondary channels; however since 2004 LTRMP biologists have documented increasing trends of percent frequency of occurrence of submersed floating-leaf and emergent vegetation in upper and lower Pool 4. The isolated and contiguous backwaters below Pepin are generally rich in submerged species." Achieving the TP and Chl-a criteria and reductions. (Lake Pepin Eutrophication TSD, p. 35)
>
> Extensive fishery studies have been conducted in these pools and in general indicate a very robust and healthy fishery. Dietermann (2009) in an assessment of Pools 3-9 notes, "Fish populations between Hastings, Minnesota and the Iowa border were generally healthy. Generally, good recruitment and growth of most game-fish species has occurred since 1994." In reference to Pool 5, he notes, "Aquatic habitat conditions were generally good to excellent throughout the pool. Dense and diverse beds of SAV were widespread and prevalent in most aquatic areas surveyed. This was the first year since monitoring began in 1993 that SAV was observed growing in portions of the lower pool in depths greater than nine feet (personal observation)." Similar notes on good habitat and extensive beds of submerged aquatic vegetation are noted for Pools 6 and 7 as well. In summary he notes "Aquatic habitat conditions were again very poor in the Lower Vermilion River; improving into the "good" range in Pool 3; and generally excellent from the lower portion of Pool 4 including the foot of Lake Pepin through Pools 5, 5A, 6, 7, 8, and upper Pool 9. Depth of observed SAV, in some pools, increased to levels (10 feet) not seen during the 16 years of this monitoring program. Even Pool 3 aquatic habitat conditions improved to the best condition measured during this program." Fish populations were described as generally healthy and stable. (Mississippi River pools Eutrophication TSD, p. 9)
>
> There are fewer survey reports for Pool 1 and the Mississippi River at Anoka. A 2009 standard lake survey report for Pool 1 (MDNR 2009) notes "Compared to the previous population assessment conducted in 1995, smallmouth bass abundance has increased significantly." The report goes on to note, "Looking at the number of gamefish sampled compared to the total number of fish sampled, the proportion of gamefish has increased. In 2009, six gamefish species comprised 68.9 percent of the total number of fish sampled. In 1995, smallmouth bass and walleye represented 11.6 percent of all fish sampled. Northern pike, channel catfish, flathead catfish and white bass were not sampled in 1995, while they were seen in 2009." Survey information and anecdotal information for the

> reach from the Coon Rapids Dam to the Crow River mouth suggests a good smallmouth bass fishery based on increased numbers of sampled fish, angler usage and monitoring of tournaments. As with the other surveys reviewed and noted in this report, MDNR fishery managers caution that valid statistical comparisons cannot be made among surveys over time in a given pool or among pools for a variety of reasons associated with sampling technique, location etc. (*e.g.* Dodds 2010, personal communication). Overall, a consistent theme emerges that suggests improvements in the fishery over time and high usage by anglers. (Mississippi River pools Eutrophication TSD, p. 10)

MPCA also evaluated the TP thresholds derived from the LTI UMR-LP model runs using two independent lines of evidence: diatom-based TP concentrations and water quality criteria for the Mississippi River from the adjoining state of Wisconsin. This evaluation indicates all three lines of evidence (the model runs plus the two additional lines of evidence) provide a very similar result:

> Based on sediment-diatom inferred TP 100 μg/L is above pre-European TP. However, pre-European P has not been the primary basis for establishing Minnesota's lake eutrophication standards. A value of 100 μg/L is well within Lake Pepin's range of diatom-inferred TP for c1900-1960 (Est. #1 and #2, Figure 14 in Exhibit EU-6). This is an important period as it included: establishment of the lock and dam system, major land clearance for agriculture, initial urbanization of the seven county metropolitan area, centralization of municipal wastewater and can serve as somewhat of a "modern-day" benchmark. Mississippi River water-quality was not pristine during this time period; however it can be argued that excess sediment loads from land clearance and organic material from untreated wastewater were the primary factors impacting water quality and aquatic life uses during this era based on accounts by Anfinson (2003; in Exhibit EU-6). A similar timeframe was used by the St. Croix Basin Water Resources Planning Team when proposing water quality goals for Lake St. Croix
>
> The state of Wisconsin completed promulgation of TP standards for rivers and lakes as of December 2010. Their standard for medium to large rivers in Wisconsin, which would include the Mississippi River, is 100 μg/L (state of Wisconsin Natural Resources Board 2010; Exhibit EU-27). Sullivan (WDNR 2010, personal communication; in Exhibit EU-6) and Baumann (WDNR 2010, personal communication) indicated this is Wisconsin's intended numeric standard for Pepin as well (Exhibit EU-6). (Eutrophication Sonar, p. 70)

IV.D.3. Minnesota's site-specific eutrophication criteria for the Mississippi River pools and Lake Pepin are based on sound scientific rationale and protective of Lake Pepin's recreation and aquatic life designated uses

MPCA's approach provides a sound scientific rationale for establishment of eutrophication criteria for Lake Pepin and the Mississippi River pools that are protective of designated recreational and aquatic life uses.

With regard to recreational uses, there is sound scientific rationale in using maximum chlorophyll *a* as the basis for the Minnesota TP and chlorophyll *a* criteria, in that the published literature documents that recreational users associate 50 μg/L maximum chlorophyll *a* and higher with severe nuisance algal blooms that render the water less suitable for swimming.

MPCA's use of the LTI UMR-LP model in evaluating relationships among summer-mean chlorophyll *a*, maximum chlorophyll *a*, and TP is scientifically sound in that nutrient response models for criteria development are supported by EPA guidance (EPA Nutrient Criteria Development Guidance for Streams, 2000, pp. 13-14):

> Three general approaches for criteria setting are discussed in this manual: (1) identification of reference reaches for each stream class based on best professional judgment (BPJ) or percentile selections of data plotted as frequency distributions, (2) use of predictive relationships (*e.g.*, trophic state classifications, models, biocriteria), and (3) application and/or modification of established nutrient/algal thresholds (*e.g.*, nutrient concentration thresholds or algal limits from published literature).

The use of models to evaluate TP/chlorophyll *a* relationships in Lake Pepin and the Mississippi River Pools system also is demonstrated as scientifically sound as supported by the Lake Pepin TMDL Science Advisory Panel (SAP). (Mississippi River pools TSD, p. 1):

> As a part of the Lake Pepin Total Maximum Daily Load (TMDL), the MPCA proposed site specific criteria for Lake Pepin. This work was done in concert with Lake Pepin TMDL Science Advisory Panel (SAP). Members of the SAP, including the Minnesota Department of Natural Resources (MDNR), Wisconsin DNR (WDNR), Metropolitan Council Environmental Services (MCES) and others, provided review and comment on the proposed criteria. The criteria were developed based on long-term data collections, modeling conducted by Limno Tech Int. (LTI) and a variety of research in support of the Lake Pepin TMDL…As a result, the SAP recommended the MPCA move forward with an analysis of data for this overall system with the intent of developing eutrophication criteria for the rivers, pools, and Lake Pepin.

Further, adaptation of the relationships from the LTI UMR-LP model to derive specific chlorophyll *a* and TP thresholds for Lake Pepin and the Mississippi River pools is scientifically sound. That the shorter residence periods of the Mississippi River pools, as compared to the residence period of Lake Pepin, would result in lower response of chlorophyll *a* to TP is supported by both MPCA's conceptual model of eutrophication enrichment (Eutrophication TSD, pp. 3-6) and EPA's conceptual model (EPA Stressor-response Guidance, 2010, pp. 5-13). Accordingly, it is scientifically sound to adjust the chlorophyll *a* component of the criteria in the Mississippi River pools. Similarly, that the LTI UMR-LP model likely overstates in-lake chlorophyll *a* response to TP is supported by results of runs of the model, which show that concentrations entering the upper portion of Lake Pepin are higher than those of the lower portions of Lake Pepin and the lake as a whole. (Lake Pepin Eutrophication TSD, p. 32). Minnesota's eutrophication criteria are demonstrated to be scientifically sound by MPCA's evaluation of other lines of evidence, which indicate very similar thresholds.

With regard to aquatic life uses, Minnesota's use of Lake Pepin fisheries data provides a sound scientific rationale for concluding that the criteria are protective of aquatic life uses.

For these reasons, the approach used by MPCA in setting eutrophication criteria for the Mississippi River pools and Lake Pepin and the resulting eutrophication criteria are based on a sound scientific rationale and are protective of designated aquatic life uses.

V. Total Suspended Solids (TSS) Criteria for Rivers and Streams, Mississippi River Pools and Lake Pepin

MPCA replaced Minnesota's statewide Nephelometric Turbidity Units (NTU) turbidity criterion with regionally-based TSS criteria for rivers and streams to provide a measure of suspended particles in rivers and water clarity. MPCA's purpose for revising the turbidity WQS was "based on the need to . . . :

1. add regional and water body-specific flexibility to the application of the standard;
2. add time-related components to address stormwater events; and
3. replace the existing measurement for turbidity in NTU to a more accurate TSS analytical method." (SONAR, Book 3, p. 5)"

MPCA identified several weaknesses in the NTU standard, including excessive measurement variation due to particle composition in water, variation among meters, and poor documentation of what a turbidity unit is (TSS TSD, p. 8). Minnesota also considered the NTU standard problematic because it is not concentration-based and therefore not amenable to load allocations or permitting, and consisted of a single statewide criterion that was not specifically related to aquatic life protection.

MPCA adopted the new TSS-based criteria to protect aquatic life uses (see Table V.1). Excess turbidity can degrade aquatic life uses and can significantly degrade the aesthetic appeal of a waterbody to the point that people are less likely to use the waterbody for recreation. Aquatic organisms may have trouble finding food, gill function may be affected, and spawning beds may be buried. MPCA's review of the scientific literature identified a number of studies where suspended sediment was linked to adverse impacts on aquatic organisms including fish and invertebrates. The adverse impacts include visibility impairment interfering with foraging, impacts on abundance and diversity of invertebrates, lower growth rates in fish thought to be related to increased energy expenditure in searching for prey in turbid water, and reductions in fish species diversity from habitat degradation associated with increased siltation (TSS TSD, p. 15-16).

Table V.1. River TSS Criteria

Use Classification	River Region	TSS mg/L	Frequency & duration
Class 2A	statewide	10	Must not be exceeded more than 10% of the time over a multiyear data window; the assessment season is April through September.
Class 2Bd & Class 2B	Northern	15	
	Central	30	
	Southern	65	
	Red River mainstem	100	
Lower Mississippi Mainstem	Pools 2 - 4	32	Must not be exceeded more than 50% of the summers over a multiyear data window; the assessment season is April through September.
Lower Mississippi Mainstem	Below Lake Pepin	30	

V.A. TSS criteria for protection of aquatic life for rivers and streams other than the Red River, Mississippi River pools and Lake Pepin

V.A.1. TSS criteria for rivers and streams other than the Red River, Mississippi River pools and Lake Pepin

As noted above, MPCA adopted the following TSS criteria for rivers and streams other than the Red River, Mississippi River pools and Lake Pepin (Table V.2, below):

Table V.2. TSS Criteria for Certain Rivers and Streams

Use Classification	River Region	TSS mg/L	Frequency & duration
Class 2A	statewide	10	Must not be exceeded more than 10% of the time over a multiyear data window; the assessment season is April through September.
Class 2Bd & Class 2B	Northern	15	
	Central	30	
	Southern	65	

V.A.2. How Minnesota derived its TSS criteria for rivers and streams other than the Red River, Mississippi River pools and Lake Pepin

MPCA derived its criteria for TSS for rivers and streams other than the Red River, Mississippi River pools and Lake Pepin using a method that parallels the method it used to derive its multi-indicator eutrophication criteria for rivers and streams. The same ecoregions as used for the eutrophication criteria are used for the TSS criteria (TSS TSD, p 13). The TSS criteria are derived using a stressor-response approach to relate TSS to support of aquatic life uses. The TSS criteria are based on biological data and TSS data collected from rivers and streams in Minnesota. TSS data from STORET were used only when specific selection criteria were met, including having at least 10 records and TSS sample collection within 5 years of biomonitoring sampling. All data was linked to assessment units for the analyses. Storm-event data were specifically excluded from the TSS data set as non-representative, biased data (TSS TSD, p. 18 and p. 25). Both fish and macroinvertebrate data from MPCA's biomonitoring were used in developing the TSS standard. Sites identified as channelized were eliminated from the final data set to reduce habitat modification effects on the data. Minnesota calculated the 90th percentile TSS concentration for each assessment unit to use for the subsequent analyses to identify TSS thresholds. The 90th percentile was based on MPCA's assessment requirement that, for TSS non-impairment, more than 90% of the TSS measurements must be below the criterion (TSS TSD, p. 18).

Minnesota's TSS criteria generally apply to rivers and streams statewide, with ecoregional and waterbody specific criteria that apply seasonally (April – September) over a multiyear period. According to Minnesota, "the type of TSS that adversely impacts aquatic life . . . is the mineral or nonvolatile fraction of TSS" (SONAR, Book 3, p. 12) and "most TSS from nonpoint sources comprises the majority of the nonvolatile suspended solids in Minnesota's rivers and is driven by storm events, it is appropriate for the WQS to focus on long-term rather than daily concentrations. As such, the MPCA is proposing TSS numeric criteria that are seasonal and based on a long-term, multiyear approach to data assessments." (SONAR, Book 3, p.3) As described below in Sections V.B and V.C of this document, since large rivers can be functionally different from their tributaries, Minnesota assigned mainstem-specific TSS criteria to the Red River of the North and the Mississippi River below the mouth of the Minnesota River.

V.A.3. Minnesota's TSS criteria for rivers and streams other than the Red River, Mississippi River pools and Lake Pepin are based on sound scientific rationale and protective of designated aquatic life uses

EPA does not have published guidance on scientific approaches states should consider taking for developing aquatic life criteria explicitly for TSS. EPA has developed criteria derivation methods regarding toxic effects on aquatic life (1985), but these methods have limited applicability to constituents, like nutrients and TSS, whose principle mode of action is not direct toxicity. For nutrients and TSS, the principle effects are indirect and occur through a series of steps that ultimately result in disruptions to the physical and/or chemical conditions of the aquatic organisms being evaluated: *i.e.*, TSS and nutrients are "stressor" pollutants whose adverse impacts can be analyzed based upon the "response" that occurs in the aquatic ecosystem to increasing levels of the stressor pollutant. Additionally, confounding variables make the evaluation of effects difficult to replicate in laboratory studies. As described above in Section IV of this document, EPA's Stressor-response Guidance sets forth a four-step process that can provide a sound scientific rationale for developing criteria for one type of pollutant – nutrients – that behaves in this manner. Given the similarities in how both nutrients and TSS impact aquatic life, there is a sound scientific rationale for using the same four-step process described in the Stressor-response Guidance to derive TSS criteria.

V.A.3.a. Step 1: Conceptual model development

Section V.B. of the TSS TSD and section 2. A. of the SONAR, Book 3 provide a narrative description of Minnesota's working conceptual model for ways in which TSS impacts aquatic life uses in rivers and streams based on the scientific literature. The discussion in the TSS TSD and SONAR indicates that impacts of increased amounts of TSS on aquatic communities occur, as described in the scientific literature, because of the impact of shading on primary producer communities (algae and plants), degradation of habitat and loss of habitat distinction (less distinction between runs, riffles and pools) and corresponding impacts on diversity of aquatic organisms, impacts on the ability of organisms to locate prey and mates and avoid predators, and direct physical impacts to aquatic organisms from exposure to suspended sediments (for example, impacts on gill surfaces). This narrative conceptual model predicts that there will an inverse relationship between increases in TSS and measures of biological integrity; as TSS increases, biological integrity as measured using various biological assessment metrics for macroinvertebrate and fish, will decrease. As described in MPCA's documentation, MPCA's conceptual model is consistent with the scientific literature such that the model is based on a sound scientific rationale.

V.A.3.b. Step 2: Exploratory data analysis

Minnesota used scatter plots of biomonitoring data to select TSS-responsive biological metrics (serving as measures of aquatic life health) for the quantile regression and changepoint analyses. The metrics selected to represent aquatic life health included ten metrics for warmwater fish communities and eight metrics for invertebrates (TSS TSD, p. 19-20). Fourteen metrics were selected for the coldwater fish communities, the same ten as for the warmwater fish plus an additional four coldwater-specific fish metrics) (Table V.3 below, from TSS TSD, p. 35 & 37).

Table V.3. Fish and macroinvertebrate metrics used to develop TSS concentration thresholds

Fish Metrics	**Invertebrate Metrics**
% Benthic Feeders	% Collector-Filterers
% Carnivore	% Intolerant
% Centrarchid-Tolerant	% Long Lived
% Herbivore	% Odonata
% Intolerant	% Plecoptera
% Long Lived	% Scraper
% Perciformes-Tolerant	% Shredder
% Riffle	% Tricoptera
% Sensitive	
% Simple Lithophils	
% Darters+Sculpins (coldwater)	
% Detritivores (coldwater)	
% NativeCold+Cool (coldwater)	
% Mature$\geq$4 Years (coldwater)	

MPCA's approach to exploratory data analysis was based on the same sound scientific rationale as that described in EPA's Stressor-response Guidance. In particular, MPCA's exploratory evaluation of TSS was consistent with the mechanism by which TSS impacts aquatic life in MPCA's conceptual model as a parameter that is a strong determinant of biological condition at a site. Additionally, MPCA used scatterplots, as recommended in the Stressor-response Guidance, to visualize the concentration range over which TSS may be adversely impacting aquatic life and to identify measures of aquatic community health that are sensitive to TSS for use in the subsequent step of criteria derivation. Consequently, MPCA's approach to exploratory data analysis was based on a sound scientific rationale.

V.A.3.c. Step 3: Stressor-response relationship evaluation and criteria derivation

V.A.3.c.i. Classification of waterbodies

Historically, attempts to derive water quality criteria for nutrients and certain other parameters have recognized ecoregional differences in setting criteria. EPA's Nutrient Criteria Development Guidance for Streams (2000) cites previous work in support of incorporating regionalization into criteria development:

> Ecoregions are based on geology, soils, geomorphology, dominant land uses, and natural vegetation (Omernik 1987; Hughes and Larsen 1988) and have been shown to account for variability of water quality and aquatic biota in several areas of the United States (*e.g.*, Heiskary *et al.* 1987; Barbour *et al.* 1996). (p. 20)
>
> The ecoregional classification system developed by Omernik (1987) is based on multiple geographic characteristics *(e.g.*, soils, climate, vegetation, geology, land use) that are believed to cause or reflect the differences in the mosaic of ecosystems. Omernik's original compilation of national ecoregions was based on a fairly coarse (1:7,500,000) scale that has subsequently been refined for portions of the southeast, mid-Atlantic, and northwest regions, among others (Omernik 1995). (p. 21)

EPA's current 304(a) criteria recommendations for rivers and streams published in 2000 are organized by ecoregions to reflect clear differences in expected nutrient conditions in rivers in streams between different parts of the country. In the same way, MPCA determined that background concentrations of TSS varied by ecoregion in Minnesota as did biological response to TSS. Based on these observations. MPCA divided the state into three TSS ecoregions, largely along the recommendations of EPA's national recommended nutrient criteria, and conducted the statistical analysis for threshold derivation for each ecoregion separately. The resulting criteria reflect the differences in expected background concentrations and TSS response thresholds across Minnesota. Page 13 of the TSS TSD provides MPCA's rationale for ecoregionalization of Minnesota for purposes of developing TSS criteria:

> V.A. Use of River Nutrient Regions:
> We are measuring a different dimension of suspended solids as we transition from an NTU WQS to a TSS WQS, but the intent has not changed – the protection of aquatic life. Concurrently with the development of the revised turbidity WQS is the development of river nutrient WQS [Heiskary *et al*, 2010]. One important component of that effort is the development of River Nutrient Regions [Heiskary & Parson, 2009]. Many of the watershed dynamics that contribute to excess nutrients in rivers are very similar to the watershed dynamics that contribute to excess turbidity. As a result, the same statewide mapping schema used for the river nutrient WQS will be used for the draft TSS WQS (Figure 1).

River Nutrient Regions are mainly ecoregion-based, but the borders between regions were studied extensively and some area-specific changes have been made [Heiskary & Parson, 2009]. Using similar maps will minimize confusion as to what standards apply where.

The SONAR, Book 3 elaborates on this further. Table 3-1 from page 10 in the SONAR, Book 3, shows that there are clear ecoregional differences in both biological response thresholds and the reference condition based thresholds as well as differences between coldwater and warmwater rivers and streams. Table 3-1 is reproduced below as table V.4.

Table V.4. Reproduction of "Table 3.1 Biological and Chemical Summaries by Region," from the SONAR, Book 3, page 10.

Regional water quality criteria (mg TSS/L)	**Reference or least impacted TSS water quality data statistical test recommendations**	**Fish and invertebrate Index of Biotic Integrity statistical test recommendations**	**Combined & rounded as appropriate**
All Class 2A waters (Trout Streams)		7	10
Northern River Nutrient Region	16	14	15
Central River Nutrient Region	31	24	30
Southern Nutrient Region	60	66	65
Red River mainstem – Headwaters to Border		100	100
For the criteria above, concentration can be exceeded no more than 10 percent of the time. The assessment season is April through September			
Lower Mississippi River mainstem – Pools 2 through 4; this criterion has already been approved by the EPA – it is included here for information purposes		32	32
Lower Mississippi River mainstem – below Lake Pepin to the State line		30	30
For the Lower Mississippi River mainstem criteria above, summer average TSS concentrations must be met in at least one half of the time. The assessment season is June through September			

MPCA's determination that background TSS concentrations and TSS biological metric thresholds vary by nutrient ecorgegion and that ecoregional criteria are appropriate across Minnesota is supported by Minnesota's data and so is based on a sound scientific rationale. MPCA's decision to use the nutrient ecoregions for TSS is based on a sound scientific rationale given the data presented in Table V.4, above, and simplifies implementation by using the same maps and ecoregion boundaries for TSS as for nutrients. Further, ecoregionalization of the TSS criteria allows MPCA to better tailor the criteria to the aquatic life uses in each ecoregion and waterbody type; avoiding being either over or under protective of aquatic life uses. For the reasons provided above, EPA finds Minnesota's classification of rivers and streams by ecoregion and coldwater and warmwater for protection of aquatic life uses is based on a sound scientific rationale.

V.A.3.c.ii. Criteria derivation for the ecoregions and for the coldwater fisheries class

EPA's Stressor-response Guidance provides a compilation of statistical tools that are widely used in the science community for deriving thresholds for stressor-response relationships. Those statistical tools are described on pages 32-34 and pages 49-55 of the guidance. The recommended tools include simple linear regression, quantile regression, non-parametric regression curves (*i.e.*, "smoothing" techniques), and changepoint analysis. MPCA utilized these approaches in deriving its TSS criteria. MPCA's specific application of these tools and how its approach is based on a sound scientific rationale is described in detail, below.

Selection of candidate thresholds. MPCA used the results of both the quantile regression and changepoint analyses as lines of evidence to relate TSS to biological metric responses and aquatic life use support in deriving the ecoregional criteria and coldwater fisheries criteria. For the quantile regressions, piece-wise regressions were conducted to identify TSS concentrations on the response gradient corresponding to where the first changes to biology occurred and where most changes have occurred. Specifically, candidate TSS thresholds were selected based on the midpoint, where the results indicated a three-piece regression, or the single breakpoint, where the results indicate a two-piece regression. The 75th percentile, as opposed to a measure of central tendency, was used for the quantile regressions, due to the presence of other stressors that likely are influencing biological response. (TSS TSD, p. 21) For the changepoint analysis, the TSS concentration corresponding to the greatest amount of change to the biological metrics was selected as the threshold (TSS TSD, p. 22).

The 25th percentile of threshold concentrations from the pooled quantile regressions and changepoint analyses in Table V.4 above for each river region and the cold water classification was selected by MPCA as the final TSS value for the stressor response line of evidence. MPCA determined that selecting the 25th percentile would ensure protection of most metrics including the most sensitive metrics. (TSS TSD, p. 23) Consistent with the approach used for the multi-parameter eutrophication criteria, thresholds were included in the final pooling only where the piecewise regression analyses fit the Fisher F-test and produced lower breakpoints or only where the changepoint analyses produced statistically significant thresholds. (TSS TSD, p. 21-22)

Generally, threshold concentrations increased from the north to south. Southern thresholds were considerably higher than the northern and central thresholds. More fish metrics than invertebrate metrics produced threshold concentrations that met the criteria for inclusion in the final pooling. In particular, because of the small invertebrate dataset for coldwater, the only threshold concentrations that were determined for coldwater were based on fish.

MPCA provided summary statistics for the quantile regressions and changepoint (TSS TSD, pp. 35-50) to demonstrate that the relationships used to generate the pool of candidate thresholds are statistically significant. Because the relationships are statistically significant, MPCA determined that the resulting TSS criteria are reliable indicators of aquatic life use protection.

MPCA's approach for deriving TSS thresholds is consistent with EPA's stressor-response Guidance and is based on a sound scientific rationale. The indicator parameter comprising the criteria (TSS) demonstrates significant relationships to measures of aquatic community health (*i.e.*, macroinvertebrate and fish metrics) consistent with MPCA's conceptual model in order to protect designated aquatic life uses. MPCA used sound statistical analysis tools for deriving thresholds to determine TSS concentrations necessary to ensure that most measures of aquatic community health are protected. In particular, MPCA's approach to evaluation of the stressor-response relationships and identification of response thresholds is consistent with EPA's Stressor-response Guidance. Further, MPCA's derivation method of using the 25th percentile of all thresholds obtained by changepoint analysis and piecewise regressions effectively considers only those thresholds that occur on the early portions of the response curves. For these reasons, MPCA's approach to evaluation of the stressor-response relationships was based on a sound scientific rationale.

V.A.3.d. Step 4: Evaluate stressor-response relationships and document analysis

As the final step in the derivation of criteria that are protective of aquatic life uses, EPA's Stressor-response Guidance recommends that the results of stressor-response based criteria derivation be systematically evaluated for scientific defensibility:

> Before finalizing candidate criteria based on stressor-response relationships, one should systematically evaluate the scientific defensibility of the estimated relationships and the criteria derived from those relationships. More specifically, one should consider whether estimated relationships accurately represent known relationships between stressors and responses and whether estimated relationships are precise enough to inform decisions. (EPA Stressor-response Guidance, p. 65)

The guidance recommends that the steps that should be included in the evaluation process are validation of the estimated stressor-response relationships, consideration of implementation issues, and documentation of the analysis used to derive the criteria. (EPA 2010, p. 65-71) MPCA's method of deriving TSS criteria includes each of these elements. A detailed description of MPCA's evaluation method is provided below. In summary:

- MPCA evaluated the results of its stressor-response based thresholds against independent threshold estimates of the same indicators, based on different locations, data sets, and analytical tools.
- MPCA addressed criteria implementation through ecoregionalization and classification by fisheries type of the criteria with the same ecoregionalization map as Minnesota used for nutrients. This accounts for ecoregional differences observed in the data and simplifies implementation.
- MPCA documented its criteria derivation methodology, including criteria validation steps, extensively and transparently in its TSS TSD and its public rulemaking documents, most notably, the SONAR, Book 3.

The Stressor-response Guidance recommendations include use of *a posteriori* (*i.e.*, after having derived thresholds on stressor-response relationships) methods of evaluating the criteria:

> *A posteriori* approaches for evaluating whether an estimated stressor-response relationship is sufficiently accurate compare the relationship with other independent estimates of the same relationship. One such approach would be to compare an estimated relationship with similar

> relationships documented in other studies. Observing a similar relationship in a different location and data set would lend support to the idea that the estimated relationship in the current study was accurate (see, for example, Jeppesen *et al.* 2005). (EPA Stressor-response Guidance, p. 66)

Previous EPA guidance (EPA Nutrient Criteria Development for Streams, 2000) also recommends that the results of stressor-response based thresholds be compared to thresholds from other lines of evidence. Although the 2000 guidance is for nutrient criteria, as with the Stressor-response Guidance, similar concepts apply to field-based TSS criteria development:

> Three general approaches for criteria setting are discussed in this manual: (1) identification of reference reaches for each stream class based on best professional judgment (BPJ) or percentile selections of data plotted as frequency distributions, (2) use of predictive relationships (*e.g.*, trophic state classifications, models, biocriteria), and (3) application and/or modification of established nutrient/algal thresholds (*e.g.*, nutrient concentration thresholds or algal limits from published literature).
>
> Initial criteria should be verified and calibrated by comparing criteria in the system of study to nutrients, chl *a*, and turbidity values in waterbodies of known condition to ensure that the system of interest operates as expected. A weight of evidence approach that combines any or all of the three approaches above will produce criteria of greater scientific validity. Selected criteria and the data analyzed to identify these criteria will be comprehensively reviewed by a panel of specialists in each USEPA Region. Calibration and review of criteria may lead to refinements of either derivation techniques or the criteria themselves. In some instances empirical and simulation modeling, or data sets from adjacent States/Tribes with similar systems may assist in criteria derivation and calibration. (pp. 12-13)

Central to Minnesota's validation of its TSS candidate thresholds based on biological responses was estimation of TSS concentrations in "reference" or "least-impacted" streams representative of the different ecoregions and waterbody types. To accomplish this, Minnesota utilized filters of STORET data (*i.e.*, to eliminate storm events) to identify "reference" or "least-impacted" sites to find the appropriate assessment units (stream segments) for calculating the TSS criteria. To classify streams as reference/least-impacted based on TSS levels, Minnesota first identified 168 non-mainstem stream reaches across the state with a minimum length of 5 miles and having sufficient data for analysis. Then those stream reaches were ranked by mean TSS level within the three River Nutrient Regions. In the North and Central River Nutrient Regions, streams with mean TSS concentrations ranked from the 30th to 50th percentile (representing a condition closer to average existing conditions) were considered "reference" streams. Since Minnesota considers the streams in the South River Nutrient Region to be more impacted, the 10th to 40th percentiles of the mean TSS concentrations were used to designate "reference" streams. Minnesota used the 10th percentile concentration from the TSS frequency curve (from reference streams) for each river nutrient region as the recommended TSS water quality criterion for that region (TSS TSD, p. 25).

The reference stream values, biologically-based stressor-response thresholds, and final criteria are provided in tabular form in Table 3-1 on page 10 of the SONAR, Book 3 (reproduced above in this document as table V.4). MPCA evaluated the multiple lines of evidence in determining the final criteria values. MPCA's selection process for the final criteria is explained on page 27 of the TSS TSD:

> The recommendations from the section above [reference streams] were combined with those from the bio-statistical sections above, using best professional judgment regarding the multiple lines of information. The resulting draft criteria are shown in Table 6. When developing TSS WQS that will be used to protect the aquatic life designated use, the preferred approach is to use biological data to develop the TSS criteria. When this is not possible, the use of reference streams provides a reasonable alternative. Because biological datasets with comparable TSS were sparse and TSS reach datasets were comparatively more robust, the results were combined. Because of the differences in the types of data and the types of statistical tests used, the approach used to combine the two approaches was a narrative-type Best Professional Judgment [BPJ] & Weight of Evidence [WOE] approach.

MPCA's approach is consistent with EPA guidance, which recommends that the different lines of evidence be compared and weighed qualitatively in selecting a final value. (EPA Stressor-response Guidance, p. 71)

> If several different response variables have been analyzed, then the different candidate criteria derived for each variable should be compared and discussed. The relative precision and accuracy of stressor-response relationships used to derive different candidate criteria can be compared, and used qualitatively to weight different candidate criteria when selecting a final value. Also, candidate criteria derived using other methods (*e.g.*, reference site distributions, literature values) can be compared qualitatively with criteria derived using stressor-response relationships.

For these reasons, MPCA's use of other lines of evidence to evaluate its piecewise regression and changepoint analysis-based thresholds and its final criteria selection process is based on sound scientific rationale.

V.A.3.e. Conclusion regarding Minnesota's TSS criteria for protection of aquatic life for rivers and streams other than the Red River, Mississippi River pools and Lake Pepin

For the reasons described above, EPA determines in accordance with 40 CFR 131.5(a)(2) and 131.11(a) that Minnesota's TSS criteria for rivers and streams are based on sound scientific rationale and protective of Minnesota's aquatic life use designations.

V.B. TSS criterion for protection of aquatic life for the mainstem of the Red River

V.B.1. TSS criterion for the mainstem of the Red River

MPCA adopted the following TSS criterion for the mainstem of the Red River (Table V.5):

Table V.5. Red River Mainstem TSS Criterion.

Use Classification	River Region	TSS mg/L	Frequency & duration
Class 2Bd and Class 2B	Red River mainstem	100	Must not be exceeded more than 10% of the time over a multiyear data window; the assessment season is April through September.

V.B.2. How Minnesota derived its TSS criterion for the mainstem of the Red River

As described above, MPCA used an ecoregion-based approach to develop TSS criteria for three large regions (North, Central and South), each of which span thousands of square miles and encompass hundreds of waterbodies that generally have similar characteristics with other waterbodies within their own ecoregion. In developing a TSS criterion for the mainstem of the Red River, MPCA effectively treated the mainstem of the Red River as its own "ecoregion," due to the fact that:

> The Red River is known for its high concentration of suspended solids. The fine clay and silt lake plain sediments of the region are easily suspended, and tend to stay in suspension even during relatively long low-flow conditions. Red River median concentrations of TSS ranged from 58 mg/L to 342 mg/L for 2003-2004 (see detailed references in Exhibit TSS-1). (TSS SONAR, p. 11).

Notwithstanding these elevated TSS concentrations, biomonitoring data for the Red River indicated that most of the sites within the Red River attain their aquatic life use designations. Specifically,

> Despite the elevated TSS concentrations that exist within the Red River, fish Index of Biotic Integrity (IBI) scores in the Red River ranged from fair to good (see detailed references in Exhibit TSS-1). (Note: a high IBI score is an indication of a healthy biological community and a low score is indicative of poor water quality.) In spite of the input from a multitude of potential suspended sediment pollution sources, IBI scores did not decrease with increasing distance downstream. Rather, some of the highest scoring sites were located nearest the Canadian border where TSS levels were highest. (TSS SONAR, p. 26)

Because existing TSS levels in the mainstem of the Red River protect the applicable aquatic life use designations, MPCA determined that existing TSS levels in the Red River could serve as the basis for deriving TSS criteria protective of the aquatic life use designations for the Red River:

> With these factors in mind, for the Red River, the MPCA is proposing a TSS standard specific to the reach that begins at the headwaters of the Red River near Breckenridge, Minnesota. This reach of the Red River typically exhibits the lowest TSS concentrations and for this rulemaking will be considered the "least impacted". The 90th percentile TSS concentration for this Assessment Unit Identification was calculated as 106 mg/L. However, given this dataset being representative of a less impacted, but not reference stream condition, it is reasonable to provide an additional five percent margin of safety, so that 100 mg/L of TSS is being proposed as the TSS WQS for the Red River from the headwaters to the Canadian border. (TSS SONAR, p. 26)

V.B.3. Minnesota's TSS criterion for the mainstem of the Red River is based on sound scientific rationale and protective of designated aquatic life uses

MPCA's approach provides a sound scientific rationale for establishment of the TSS criteria for the mainstem of the Red River that are protective of designated aquatic life uses. Specifically, there is sound scientific rationale for concluding that (1) in light of existing biomonitoring and TSS ambient monitoring data, existing TSS levels in the mainstem of the Red River protect designated aquatic life uses, and (2) a single criterion for the Red River based on the ambient TSS concentrations associated with that portion of the Red River that typically exhibits the lowest TSS concentrations – namely the headwaters – will be protective of aquatic life uses throughout the entire mainstem of the Red River.

V.C. TSS criteria for protection of aquatic life for the Mississippi River pools and Lake Pepin

V.C.1. TSS criteria for the Mississippi River and Lake Pepin

MPCA adopted the following TSS criteria for the Mississippi River and Lake Pepin (Table V.6):

Table V.6. TSS Criteria for Mississippi River pools and Lake Pepin.

Use Classification	River Region	TSS mg/L	Frequency & duration
Lower Mississippi Mainstem	Pools 2 - 4	32	Must not be exceeded more than 50% of the summers over a multiyear data window; the assessment season is April through September.
	Below Lake Pepin	30	

V.C.2. How Minnesota derived its TSS criteria for the Mississippi River pools and Lake Pepin

As described above, MPCA used an ecoregion-based, stressor-response approach to develop TSS criteria for three large regions (North, Central and South), each of which span thousands of square miles and encompass hundreds of waterbodies that generally have similar characteristics with other waterbodies within their own ecoregion. As with the ecoregional TSS criteria, in developing TSS criteria for Lake Pepin and the Mississippi River pools, MPCA utilized a stressor-response. However, for the Lake Pepin and the Mississippi River pools, extensive nutrient-related data were available, and accordingly MPCA was able to derive site-specific TSS criteria for Lake Pepin and the Mississippi River pools. Additionally, MPCA's stressor-response approach for Lake Pepin and the Mississippi River pools focused on a single biological response endpoint, namely coverage of submerged aquatic vegetation (SAV). MPCA determined it was scientifically sound to use SAV as the single response endpoint because extensive research in the study area indicates 1) SAV to be a key indicator of eutrophication and 2) provides extensive SAV data for criteria derivation:

> The submersed aquatic vegetation (SAV) in the lower Mississippi River has been studied for decades and is considered the keystone community for ensuring a healthy aquatic community (UMRCC, 2003). SAV are sources of food for waterfowl, serve as substrate for invertebrates and periphyton, and as habitat for larval and adult fish. SAV also helps stabilize sediments by creating quiescent areas around their stems and leaves. SAV are used by the UMRCC as a measure of ecosystem health. (TSS SONAR, p. 26)

MPCA's procedure for deriving the TSS criterion for the Mississippi River pools and Lake Pepin is described on page 11 of the TSS SONAR:

> The stretch of the Lower Mississippi River, from Pool 2 to the mouth of Lake Pepin is considered to be in the Central Region and would normally be subject to the TSS WQS applicable to that region. However, this stretch of the Mississippi is currently impaired and subject to the conditions of a TMDL. (For details on the MPCA south metro Mississippi TMDL TSS Impairment, link to the following MPCA website: http://www.pca.state.mn.us/ktqh98b.) Because the TMDL has established a site-specific standard for TSS for this stretch of river that was approved by the EPA on November 8, 2010, (Exhibit TSS-2), that TSS standard of 32 mg/L, will be listed in Minn. R. ch. 7050 for that reach, instead of the regional TSS standard of 30 mg/L that is being proposed for the remainder of the Central Region. The site-specific modified standard of 32 mg/L, as a summer average, was established on an extensive data set and historical information. The MPCA agrees that for this stretch of the Mississippi, the recommendation of the UMRCC is reasonable. A TSS WQS of 32 mg/L allows for adequate transparency for SAV to reach their target community densities. Another key document used in setting the TSS WQS for this stretch of the Mississippi River mainstem is by Sullivan *et al* (Sullivan *et al* SAV 2009.pdf) of the Wisconsin Department of Natural Resources.
>
> In regard to the stretch of the Mississippi River mainstem below Lake Pepin, the MPCA has relied on another recent document that relates light penetration to TSS (Giblin *et al*, 2010). They recommended a TSS goal of 30 mg TSS/L to maintain SAV densities below Lake Pepin. That recommendation forms the basis for the reasonableness of the proposed TSS WQS of 30 mg TSS/L as a summer average of the Mississippi below Lake Pepin and also for the rest of the rivers in the Central Region.

V.C.3. Minnesota's TSS criteria for the Mississippi River pools and Lake Pepin are based on sound scientific rationale and protective of designated uses

MPCA's approach provides a sound scientific rationale for establishment of TSS criteria for Lake Pepin and the Mississippi River pools that are protective of designated aquatic life uses. Specifically, there is sound scientific rationale in using SAV as the measure of aquatic ecosystem health and subsequently basing the TSS criteria on the protection and promotion of SAV. Minnesota previously adopted and received approval from EPA (on November 8, 2010) for a site-specific TSS criterion of 32 mg/L, as a summer average, for the Mississippi River extending from Pool 2 through river mile 780 in Pool 4 (upper Lake Pepin). In this rule MPCA is extending that TSS criterion to encompass all of Lake Pepin and downstream to dam 4. Minnesota used a more recent study that expands on the previous work providing the basis for the SAV protective TSS criterion, to support 30 mg/L as the TSS criterion for the Mississippi River below Lake Pepin.

Documents cited in the TSS SONAR, "Submersed aquatic vegetation targets for the turbidity-impaired reach of the Upper Mississippi River Pool 2 to upper Lake Pepin" (Sullivan *et al.* 2009) and "Evaluation of Light Penetration on Navigation Pools 8 and 13 of the Upper Mississippi River. USGS Technical Report 2010-T001" (Giblin, S. *et al.* 2010), identify TSS concentrations associated with light requirements of SAV in the Mississippi River pools below Lake Pepin. As such, they provide the science rationale for establishing TSS concentrations in the pools necessary for the protection of aquatic life. Specifically, the documents establish the SAV coverage necessary for protecting aquatic life, the light requirements for attaining that SAV coverage, and the site-specific TSS concentrations that are associated with the light requirements. These documents were vetted and supported by scientists familiar with the biological processes in Mississippi River pools. MPCA's approach to deriving TSS criteria for the Mississippi River pools adheres to the scientific findings in these documents. Accordingly, the approach used by MPCA in setting TSS criteria for the Mississippi River pools and the resulting TSS criteria are based on a sound scientific rationale and are protective of designated aquatic life uses.

VI. Public Comments

A substantial number of public comments were raised in Minnesota's administrative proceedings leading up to MPCA's adoption of the eutrophication criteria. MPCA considered and responded to the public comments before adopting the criteria. EPA reviewed and considered all of the public comments and MPCA's responses in deciding whether Minnesota's eutrophication criteria are based on sound scientific rationale and protect applicable designated uses. EPA generally agrees with MPCA's responses to the public comments and nothing in those comments causes EPA to conclude that Minnesota's eutrophication criteria are not based on sound scientific rationale or do not protect applicable designated uses.

VII. New and Revised Items upon Which EPA is Taking No Action Because They are Not New or Revised WQS

As explained above in Section I.A of this document, EPA determines whether a particular provision is a new or revised WQS after considering the following four questions:

> (1) Is it a legally binding provision adopted or established pursuant to state or tribal law?
> (2) Does the provision address designated uses, water quality criteria (narrative or numeric) to protect designated uses, and/or antidegradation requirements for waters of the United States?
> (3) Does the provision express or establish the desired condition (*e.g.* uses, criteria) or instream level of protection (*e.g.* antidegradation requirements) for waters of the United States immediately or mandate how it will be expressed or established for such waters in the future?
> (4) Does the provision establish a new WQS or revise an existing WQS?

Minn. R. 7050.0150, Subps. 5, 5a, 5b and 5c and Minn. R. 7053.0205, Subps. 7 and 9a do not "express or establish the desired condition (*e.g.*, uses, criteria) or instream level of protection for waters of the United States immediately or mandate how it will be expressed or established for such waters in the future" and so they are not new or revised WQS that EPA must act on under Section 303(c) of the CWA. Instead, Minn. R. 7050.0150, Subps. 5, 5a, 5b and 5c address how MPCA will utilize sampling data in determining whether specific water bodies in Minnesota are impaired while Minn. R. 7053.0205, Subps. 7 and 9a are NPDES permitting provisions pertaining to how MPCA will evaluate the need for and establish water quality based effluent limitations for TSS in NPDES permits for point sources.

VIII. Endangered Species Act Section 7 Consultation

As required under section 7 of the ESA and federal regulations at 50 CFR Part 402, EPA evaluated whether this standards action would affect federally-listed threatened or endangered species or designated critical habitat. As described in the biological evaluation, EPA determined that the action may affect, but is not likely to adversely affect, aquatic, aquatic-dependent, or wetland species in Minnesota. Further, EPA determined that the action will not destroy or adversely modify designated critical habitat. Accordingly, EPA does not expect impacts of concern to occur to listed aquatic, aquatic dependent, and wetland species or their designated critical habitat in the action area prior to the completion of consultation.

To date, EPA has initiated, but not completed, consultation with U.S. Fish and Wildlife Service on its action. EPA has determined that this approval action does not violate Section 7(d) of the ESA, which prohibits irreversible or irretrievable commitments of resources that have the effect of foreclosing the formulation or implementation of reasonable and prudent alternatives. While EPA does not believe that FWS will conclude that its action violates section 7(a)(2), its action does not foreclose either the formulation by the FWS, or the implementation by EPA, of any alternatives that might be determined in the consultation to be needed to comply with section

7(a)(2) of the ESA. By approving the standards subject to the results of consultation under section 7(a)(2) of the ESA, EPA has explicitly stated that it retains its discretion to take appropriate action if the consultation identifies deficiencies in the WQS requiring remedial action. EPA retains the full range of options available under section 303(c) for ensuring WQS are environmentally protective. For example, EPA can: work with Minnesota to ensure that the standards are revised as needed to ensure the protection of listed species, initiate rulemaking to promulgate federal standards to supersede the standards, or, in appropriate circumstances, change EPA's approval to a disapproval.

IX. Tribal Consultation

On May 4, 2011, EPA issued the "EPA Policy on Consultation and Coordination with Indian Tribes" to address Executive Order 13175, "Consultation and Coordination with Indian Tribal Governments." EPA's Tribal Consultation Policy states that "EPA's policy is to consult on a government-to-government basis with federally recognized tribes when EPA actions and decisions may affect tribal interests."

Multiple tribes (11) have resources in the state of Minnesota. In a letter dated June 3, 2014, EPA Region 5 extended an invitation to these 11 tribes to consult on Minnesota's proposed WQS for eutrophication and Total Suspended Solids (TSS) for rivers and streams in Minnesota. No tribal request for consultation was received by EPA's deadline.